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I

TERTIARY MAMMALS FROM THE AURIFEROUS GRAVELS NEAR COLUMBIA, CALIFORNIA

By John C. Merriam and Chester Stock

With two text-figures

[Issued November 1933]

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TERTIARY MAMMALS FROM THE AURIFEROUS GRAVELS NEAR COLUMBIA, CALIFORNIA

INTRODUCTION

Since their earliest exploitation for gold, the auriferous gravels of the Sierra Nevada have yielded on occasion remains of fossil mammals whose age clearly indicates the presence of deposits belonging to several divisions of the Cenozoic. Extensive hydraulic and placer mining in this region is largely responsible for the fact that many localities where fossil materials have been found in the past are now no longer accessible.

In the course of mining operations by the Springfield Development Company, two horse teeth and a fragmentary camel jaw were found in gravels and sands of the Springfield shafts Nos. 2 and 3, located one and one-half miles southwest of Columbia, California. The mammalian remains were obtained by R. W. Chaney from J. S. Cademartori, Superintendent of the Springfield Development Company.

Since the stratigraphic occurrence of the material, as determined by Professor George D. Louderback, is definitely established with reference to the Tertiary section exposed in this region, interest attaches to the age and correlation of the deposits as suggested by the relationships of the fossil mammals. Moreover, the presence of fossil plants in the sedimentary series offers, among other features, an opportunity to check the age relationships of the accumulations by the application of paleobotanical evidence.

DESCRIPTION OF VERTEBRATE REMAINS

Hipparion, near mohavense Merriam

The two horse teeth available from the Springfield shaft Number 2, Univ. Calif. Coll. Loc. A 729, represent $P\underline{4}$ and $M\underline{3}$. The premolar, No. 24246 Univ. Calif. Coll. and the molar, No. 24247, were found some distance apart. In the light of the characters presented by these teeth there seems little reason for assuming that the specimens do not belong to the same species. Possibly two individuals are represented, differing slightly in age and size. These teeth resemble each other in the strongly developed external styles, in narrowness of the fossettes and complexity of their enamel borders, and in the flattened and somewhat elongate protocone.

Nos. 24246 and 24247 are smaller than comparable teeth of *Hipparion mohavense* from the Ricardo. They resemble, however, the latter in complexity of enamel borders of the fossettes. The protocone tends to flatten slightly, more so than in the typical *H. mohavense.* Likewise, in the more elongate character of this cusp, the teeth differ from the Ricardo type. However, the character of round-oval protocone seen in the type and associated teeth of *H. mohavense* is modified somewhat in the subspecies *H. mohavense callodonte,* described also by Merriam from the Ricardo. In the characters in which *callodonte* differs from typical *mohavense* it approaches the specimens from Columbia.

In size Nos. 24246, 24247 resemble somewhat teeth of *Neohipparion gratum tehonense* described by Merriam from the Chanac formation of California. There is a more distinct tendency for the protocone to flatten in Nos. 24246, 24247 than in *N. gratum tehonense.* The fossettes may average slightly narrower than in teeth of *Neohipparion gratum* from the Snake Creek beds of Nebraska.

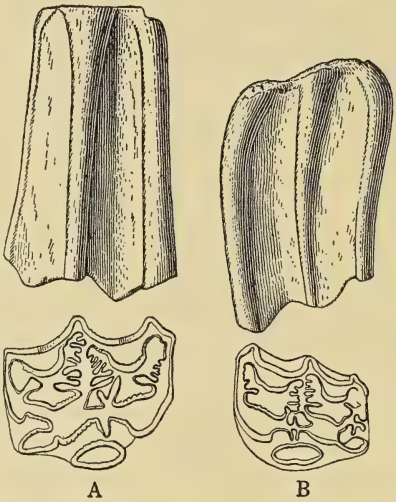

FIG. 1—*Hipparion,* near *mohavense* Merriam. A, P$\underline{4}$, No. 24246; B, M$\underline{3}$, No. 24247; lateral and occlusal views; x 1. University of California Collections. Auriferous sands and gravels, near Columbia, California.

A single tooth described from the Siestan Pliocene of the Berkeley Hills, California,[1] No. 24241 Univ. Calif. Coll., and referred to *Hipparion,* near *mohavense,* shows considerable resemblance to the horse from the auriferous gravels. No. 24246 is slightly smaller than No. 24241, but similarity between the two teeth prevails in shape of protocone and in the degree of plication of the fossette borders. The plications seem to be essentially the same in both forms, but are slightly more numerous in No. 24246. While the pli caballin is single in the premolar, it is double in the third upper molar, No. 24247. In the Siestan tooth this structure is double with a small spur extending forward from the anterior plication.

Of the several specimens with which comparisons have been made, No. 24241 appears to resemble most closely the species recorded from near Columbia. Both Nos. 24241 and 24246, while not identical in character with teeth of typical *Hipparion mohavense,* resemble specimens belonging to this group of horses.

Measurements of teeth (in millimeters)

	P$\underline{4}$ No. 24246	M No. 24247
Greatest anteroposterior diameter	21.9	19
Transverse diameter across protocone and mesostyle	19.5	14
Anteroposterior diameter of protocone	6.8	6

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[1] C. Stock, Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 13, 19–21, 1 fig., 1921.

Camelid, possibly Pliauchenia or Procamelus

Unfortunately the ramus of the mandible, No. 24248, is too fragmentary to give much information. The premolars and apparently the anterior molar have been broken away. The posterior molars are only partly preserved. This specimen came from shaft 3 (Richards shaft).

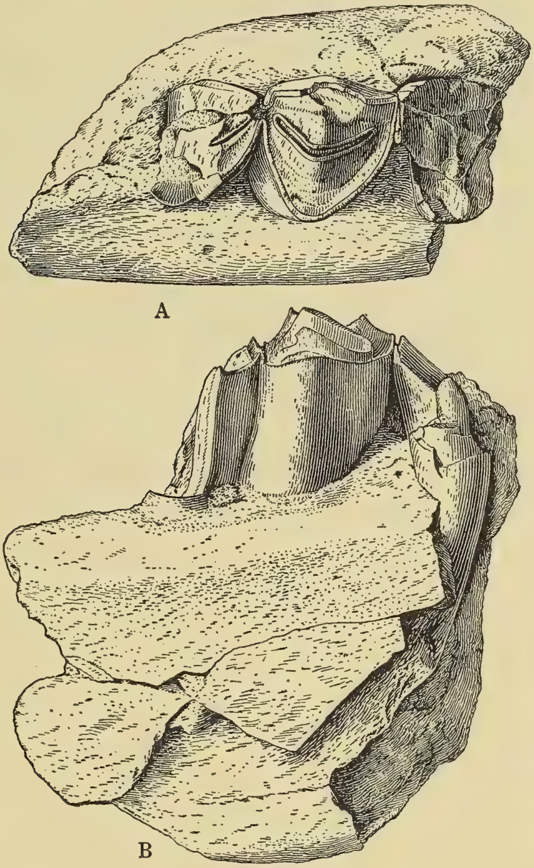

FIG. 2—Camelid, possibly *Pliauchenia* or *Procamelus*. A, B, fragment of jaw and lower dentition, No. 24248, dorsal and lateral views; x 1. Mass shown on upper side of figure 2A represents rock matrix. University of California Collections. Auriferous sands and gravels, near Columbia, California.

The specimen is larger than camel material referred to *Procamelus*, near *gracilis* from the Cedar Mountain upper Miocene, Nevada. This is shown by the size of the ramus and the individual teeth. It is larger also than some of the materials referred tentatively to *Procamelus* or *Alticamelus* from the Ricardo lower Pliocene of the Mohave Desert.

AGE RELATIONSHIPS

The scattered vertebrate remains which have been found in the auriferous gravels and associated deposits of the Sierra Nevada, although for the most part fragmentary and incomplete, are suggestive of faunal stages ranging in age from late Oligocene or early Miocene to the Pleistocene.

Whatever age relationships are indicated by the mammalian remains from the gravels and sands exposed in the Springfield mine shafts near Columbia, the most direct evidence is that afforded by the horse teeth. The genus *Hipparion* representing this material is found elsewhere in western North America associated with faunas whose ages are distinctly later than that of the faunal elements recorded from early Tertiary beds in Calaveras County.[1] Moreover, nowhere in western North America is this genus of horse recorded in Pleistocene deposits. In stage of development the two teeth represent the *Hipparion* group as it is known in such horizons as the Ricardo deposits of the Mojave Desert region, three beds having been classed with the Pliocene. A close relationship is suggested with *Hipparion mohavense* and types compared with the latter.

Until cumulative information regarding the stratigraphic position of *Hipparion* in western Tertiary deposits is of such extent as to permit clear judgment, no definite statement can be made with reference to the lower time range of this genus. Recent discussions have emphasized the possible late Miocene appearance of *Hipparion* in America. Possibly the gravels and sands in which the horse teeth and camel jaw occurred near Columbia are upper Miocene in age.

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[1] C. Stock, Proc. Nat. Acad. Sci., vol. 18, 552–553, 1932.

II

NOTES ON THE GEOLOGIC SECTION NEAR COLUMBIA, CALIFORNIA, WITH SPECIAL REFERENCE TO THE OCCURRENCE OF FOSSILS IN THE AURIFEROUS GRAVELS

By George D. Louderback

[Issued November 1933]

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NOTES ON THE GEOLOGIC SECTION NEAR COLUMBIA, CALIFORNIA, WITH SPECIAL REFERENCE TO THE OCCURRENCE OF FOSSILS IN THE AURIFEROUS GRAVELS

INTRODUCTION

The sections studied in the field were observed in Number 2 shaft and the Buchanan Tunnel of the Springfield Mining and Development Company, situated about one and a half miles west-southwest and southwest of Columbia respectively.

BUCHANAN TUNNEL

The Buchanan Tunnel exposes bedrock, a rather disintegrated and decomposed dioritic rock. Directly on this bedrock is a layer of gravel, 2 to 3 feet thick, carrying in fine sandy matrix pebbles and boulders of varying size from a fraction of an inch to a foot or more in diameter. The upper part is mostly sand with very few pebbles. The sand is not well sorted and carries very fine clayey material between the grains.

All of the pebbles and boulders are of pre-Cretaceous bedrock material, chiefly quartz, light-colored quartzite, muscovite-bearing quartzite and other siliceous metamorphic rocks and aplites. Among the less common types are black quartzite, mica schist, granodiorite and diorite. No rhyolite, andesite or other volcanic types were observed.

The larger boulders examined were all of more or less basic diorite. One large one was composed of medium-grained highly hornblendic hornblende-mica diorite of a type rather common in the restricted area of metadiorite that extends two and a half miles north and one and a half miles south of this locality. Two others were of a fine even-grained hornblende diorite, such as is common in small masses or dikes in the same area. In both of these types, the feldspars have been entirely replaced by alteration products.

The smaller pebbles are mostly fairly well rounded. Some small ones, less than half an inch in diameter, are flat and consist chiefly of quartzite and micaceous schist. A few are poorly rounded or irregular. These are mostly of mica schist.

The sands into which the gravels grade upward and the matrix of the basal gravels are of the same composition. They consist largely of fragments of quartz, both glass clear and milky, of granitic, metamorphic, and vein origin, quartzite, muscovite, biotite, bits of micaceous quartzite and siliceous micaceous schist, bits of decomposed feldspar and various accessories, such as magnetite, titanite, tourmaline, etc., more or less characteristic of granitic and metamorphic rocks.

Immediately overlying the light-colored quartzose sands and gravels is a brown, medium to coarse-grained sand, somewhat ripple marked, and some one and a half to two feet thick. The contact line is very sharp, although in places it is locally irregular. It is composed practically wholly of andesitic detritus. Following this with no apparent break is a series of sedimentary layers, frequently strikingly ripple marked, with ripples three inches or more from crest to crest. The coarseness varies in general from medium-grained sand down to aphanite silt, with an occasional thin streak or flat lens of fine gravel, carrying quartz and other bed-rock pebbles. Some of the aphanitic sediment has become somewhat flinty and a few pebbles of such material were seen just above the flinty layer. The variation in grain is not progressive, but swings back and forth through different grades of sand and fine silts. Some of the fine silts are beautifully laminated with separable laminæ, and the finest silts show color banding.

Over 30 feet of these sediments are exposed by the tunnel, and with the exception of occasional thin flat lenses of predominating bedrock gravel, the characteristic and almost the whole material is andesitic detritus. The finest more or less argillaceous materials of the silts show little of which the origin can be definitely determined under the microscope, but the thin intercalated layers of very fine sand are definitely andesitic.

It is in the fine silts of these andesitic sediments, between 25 and 35 feet above the gravels, that the fossil plants are found.

SHAFT NO. 2

Shaft No. 2 is about 4200 feet southeast of the mouth of Buchanan Tunnel. It discloses the following section:

Bedrock is exposed about 230 feet below the surface of the ground. On it rest two to four feet of gravel with sandy matrix grading upward into one to two feet of sand. As in the Buchanan Tunnel, neither the upper sand nor the gravel matrix is clean sorted, the particles varying from somewhat less than one millimeter in diameter down to clay.

The pebbles of the gravel were derived entirely from the pre-Cretaceous bedrock formations. They are chiefly quartz and quartzite with small amounts of granitic and of other metamorphic rocks. No pebbles of volcanic rocks were observed.

The sandy matrix of the gravels consists chiefly of quartz, clear glassy or milky, and quartzite, with less common muscovite, biotite, and decomposed feldspar fragments. Intergrown quartz and biotite, and quartz and tourmaline were observed. Fragments of micaceous quartzite, aplite, tourmaline, hornblende, titanite, and two small bits of gold were also noted in the sample.

Immediately overlying the light-colored quartzose sands with a sharp contact is a brown, somewhat hardened layer of medium to very fine sand, one to two feet thick. This appears to consist entirely of andesitic detritus. Above and without apparent break is a series of layers varying in grain from fine sand and silt to conglomerate with pebbles one inch or more in diameter, and except for one horizon, apparently composed chiefly or wholly of andesitic detritus up to the surface, that is, for about 225 feet. Conditions for observation were not such that every layer could be definitely examined. The cage was run slowly and stops made at brief intervals. One layer, referred to above, about 150 feet down the shaft, carried some large diorite boulders. In general the lower sediments are thin-bedded sands and silts, the upper part of the section being chiefly andesitic conglomerate. The attitude is not far from horizontal.

Above the shaft house toward the east rises a hill occupied entirely by andesitic detritus. This undoubtedly represents the upward extension of the section disclosed in the shaft and continues it 60 feet or more. At least the upper layer on the hill carries boulders of andesite one foot or more in diameter. No such coarse andesitic material was observed in the shaft.

COMPARISON OF SECTIONS

The two sections above described show very similar characters, both as regards material involved and sequence. Both bottom gravels lie on pre-Cretaceous bedrock, are made up exclusively of bedrock material, grade upward into sand entirely of bedrock detritus. In both cases the sand and the gravel matrix are not well sorted and are evidently formed under similar conditions of erosion and deposition.

The line between the older sands and the andesitic sediments is sharp. The andesitic sediments are at first fine and show alternations of sand and silt. Andesitic conglomerates are found only well up in the shaft section, well above the horizon exposed in the Buchanan Tunnel, and the large boulder masses are still higher.

The bottom gravels are evidently pre-andesitic for this locality. No pebbles or other detritus of rhyolitic origin was recognized.

As to whether the gravels are "pre-volcanic" in the sense used in the literature of the Tertiary Auriferous Gravels of the Sierra Nevada is not clear. In the absence of rhyolites in the vicinity, the gravels may have been formed during the rhyolitic period. For we may assume that the rhyolites were deposited in the main valleys and did not cover this territory.

The question may be raised as to whether these gravels may not represent the early part of the andesitic period, on the assumption that the andesites of that time may have been limited to the main Tertiary valleys and only in the latter part of the andesitic period covered the locality in question, as this locality is 5 or 6 miles from the valley of the ancient Calaveras River. However, the common observation that the earlier andesitic deposits were usually of fine detritus, as described above, and that the coarser conglomerate and agglomerates came later would suggest that we may have the earlier part of the andesitic period represented here.

The poorly sorted sands and gravel matrix and the occurrence of relatively so large a proportion of dioritic boulders, fresh biotites, etc., would lead one to conclude that these gravels do not represent the period of "deep gravels," for these consist only of materials most resistant to decomposition.

In the light of present knowledge we may conclude that the gravels exposed in the Buchanan Tunnel and Shaft No. 2 probably represent a late pre-andesitic deposit.

FOSSIL OCCURRENCES

The leaves collected by Dr. Chaney from the mouth of the Buchanan Tunnel are definitely from the fine andesitic sediments within 25 to 30 feet of its local base.

A sample of matrix of fossil leaves collected from the Buckeye Tunnel, Table Mountain, was examined under the microscope and showed fine andesitic detritus indistinguishable from samples of comparable texture collected in the Buchanan Tunnel. Judging from the geological relations and the sequence in the Table Mountain Section, it appears certain that the Buckeye Tunnel fossils came from the same general portion of the same andesitic series as the fossils from the Buchanan Tunnel.

Mr. Cademartori, Manager of the Springfield Development Company's Mine, who found the vertebrate fossils studied by Dr. Stock, claims that he found the horse teeth at the base of the gravel against the bedrock, and that the camel jaw came from the Richards Shaft at the top of the sand and below the fine brown layer which has been determined as andesitic sediment.

Some of the matrix attached to the camel jaw was removed and examined under the microscope. It is distinctly of pre-andesitic sand type as described above. Quartz is abundant, associated with muscovite, some dark-green hornblende and a little biotite, together with decomposed feldspar fragments. Some garnet and magnetite was also observed. The type of association and poor sorting of material was also the same as in the samples from the Buchanan Tunnel and Shaft Number 2 as above described.

It appears then that the two plant horizons are early andesitic and the two vertebrate horizons are at least locally pre-andesitic.

It may be further noted that the andesites above described were deposited before the establishment of the stream down whose valley the latites of Table Mountain flowed, and were eroded in the course of production of this valley.

III

PERISSODACTYLA FROM THE SESPE OF THE LAS POSAS HILLS, CALIFORNIA

By Chester Stock

With four plates

[Issued November 1933]

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PERISSODACTYLA FROM THE SESPE OF THE LAS POSAS HILLS, CALIFORNIA

INTRODUCTION

The concentration of fossil vertebrate remains at the Kew Quarry site in the Sespe deposits of the Las Posas Hills,[1] California, furnishes one of the most varied early Tertiary mammalian faunas as yet recorded from western North America. Related in age to the John Day and upper White River, this assemblage offers for the first time an adequate basis for comparing the late Oligocene mammalian history of the Pacific Coast marine province with that determined in the Tertiary continental provinces to the east of the Cascade Range and of the Rocky Mountains.

In order to reach a fuller understanding of the stage of evolution of the Kew Quarry fauna the structural features of individual members need now to be considered and the relationships of these forms determined in greater detail than was attempted in the original statement. Brief descriptions and comparisons will be given, therefore, in this and in subsequent papers.

Among the more commonly occurring mammals in the Kew Quarry fauna are the rhinoceroses of the genus *Subhyracodon* (*Cænopus*). This type is represented by many parts of skeletons in the collections of the California Institute of Technology. In contrast, the horses are known at present by a single individual. The material, though scanty, is clearly referable to the genus *Miohippus*. While furnishing an opportunity to compare the stage of development of the Equidæ in the Sespe with that found in the John Day beds of eastern Oregon and in the White River of the western Great Plains, added interest attaches to this specimen as the first documentary evidence of the occurrence of the genus in the Pacific Coast region of North America.

DESCRIPTION OF MATERIAL

Subhyracodon kewi n. sp.

Type specimen—Skull, No. 1205, Calif. Inst. Tech. Coll. Vert. Pale., Plate 1, with complete cheek-tooth dentition P$\underline{1}$–M$\underline{3}$ and alveoli for the canine and two incisor teeth. The species is named for Dr. W. S. W. Kew, who discovered this important fossil locality in the Las Posas Hills.

Paratypes—Two skulls, Nos. 1221, 1222, Calif. Inst. Tech. Coll. Vert. Pale., Plate 2, figures A and B; Plate 3, figure A.

Referred specimen—An incomplete lower jaw, No. 1224, Plate 3, figure B, and a right premaxillary with second incisor, No. 1225, Plate 3, figures C and D.

Specific characters—Size, as indicated by dentition, like that of *Subhyracodon trigonodum.* Cingulum absent on upper molars. Enamel pattern of occlusal surface in P$\underline{3}$ and P$\underline{4}$ more like *trigonodum* than like *copei, occidentale* and *tridactylum.* Accessory longitudinal rib or ribs developed on inner surface of ectoloph in P$\underline{4}$, M$\underline{2}$ and M$\underline{3}$.

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[1] C. Stock, Proc. Nat. Acad. Sci., vol. 18, 550–554, 2 figs., 1932.

Description—Viewed in the light of the many similar characters displayed, particularly by the superior dentition, the several skulls selected as type and paratypes of *Subhyracodon kewi* clearly belong to a single species. Taken collectively, these specimens permit of a detailed comparison with skulls of Oligocene rhinoceroses of the western Great Plains.

The skulls of the paratypes, Nos. 1221, 1222, unfortunately have the ends of the nasals as well as the premaxillaries missing, but retain their cranial portions. In the type, No. 1210, the cranial region for the most part is absent. In this specimen the antorbital foramen is situated above the anterior half of P$\underline{3}$. The anterior end of the right nasal is present. This element is slender and shows clearly that a pedicle for a nasal horn was absent. No. 1221, in which M$\underline{3}$ has not been fully erupted, is flattened dorso-ventrally but still displays some of the important structural features of the midcranial and basicranial regions. The postnarial notch incises the midline of the palate to a point opposite the protoloph in M$\underline{2}$. The anterior margin of this notch is not perfectly preserved. Although the orbital wall of the cranium is badly crushed, the anterior edge of the alisphenoid is partly preserved and indicates that behind this was the recess into which the optic foramen, the foramen lacerum anterius and foramen rotundum open. The alisphenoid canal and foramen ovale are shown in No. 1221, the latter opening occurring to the antero-internal side of the postglenoid process. A postglenoid foramen is present. The space between the postglenoid and posttympanic processes is broad, in which respect *Subhyracodon kewi* is like *S. trigonodum.* Posttympanic and paroccipital processes exhibit the characters seen in the White River species of *Subhyracodon.* The latter process in skull No. 1221 is in part broken away and the posterointernal fringe is imperfect. The otic region displays the periotic mass. Posterointernal to this is the foramen lacerum posterius with the stylo-mastoid foramen clearly indicated to the outer side of the latter opening, although not shown in the illustrations of this specimen. The relatively large space to the internal and antero-internal sides of the periotic represents the foramen lacerum medius. Almost midway in an oblique direction between the paroccipital process and the condyle lies the hypoglossal foramen.

In skull No. 1222 the posttympanic and paroccipital processes are better preserved than in No. 1221. The paroccipital process is closely situated to the posttympanic and is flattened anteroposteriorly with the anterior face slightly concave transversely. This process in its downward course appears to be directed forward and slightly outward.

The occiput is best shown in skull No. 1222 although badly deformed in this specimen (see Plate 3, fig. A). The indentation of lateral borders gives prominence to the superior portion of the occiput. A median crest is sharply defined principally in the upper half and is continued below to the upper lip of the foramen magnum as a broadly rounded surface. On the upper half of the occiput a broadly rounded ridge diverges on each side from the median line and extends upward to the occipital crest. Between these diverging arms and the median crest the surface of the occiput is depressed.

In the type specimen, No. 1205, the premaxillaries show the alveoli for the incisors, although the teeth are absent. The two alveoli for the incisors are situated close together with that for I$\underline{2}$ distinctly larger than the socket for I$\underline{3}$. Due to displacement and some crushing at the palatal end of the premaxillary-maxillary sutures the alveoli for the canines are not perfectly preserved. There is, however, definite evidence that this socket was present for a portion of its posterior wall is preserved on the left side. Moreover, on the right side can still be discerned the upper portion of the canine alveolus, now filled with matrix.

A portion of a right premaxillary with I$\underline{2}$ present and the alveolus for I$\underline{3}$ is shown in Plate 3, figures C and D. The anterior incisor has the characteristic shape seen in *Subhyracodon.* The alveolus for I$\underline{3}$ does not possess an anteroposterior diameter as great as that for the forward tooth, but the transverse diameter is fully as large. Although a small fragment of the maxillary adheres to this specimen, there is no trace of an alveolus for the canine. It appears probable that in at least some individuals from the Kew Quarry this tooth was absent.

In the cheek-tooth series, which is complete from P$\underline{1}$ to M$\underline{3}$ inclusive in No. 1205, P$\underline{1}$ is worn considerably and M$\underline{3}$ is not entirely erupted. P$\underline{1}$ is separated from the alveolus for the canine by a diastema measuring 30 mm. in length. The occlusal surface of the first premolar is not so greatly worn in No. 1221 as in No. 1205. The tooth approximates a triangular shape with the ectoloph reaching forward and inward, well in front of the inner side of the protoloph. Protoloph and metaloph are distinct and the former crest is distinctly smaller than the latter. A well-developed ledge or shelf is present between the inner ends of the two cross-lophs and anterior to the protoloph, extending forward to the end of the ectoloph. While internal cingula are well defined on premolars $\underline{2}$-$\underline{4}$ of the type specimen, they are entirely lacking on M$\underline{1}$ and M$\underline{2}$. The occlusal pattern of P$\underline{2}$ is molariform, for the two transverse lophs are distinct, but the posterior loph at this stage of wear has established connections with the posterior cingulum. A postfossette is therefore present in this tooth.

In P$\underline{3}$ the protoloph is broadly connected with the metaloph and this postero-internal region has fused also with the posterior cingulum. Thus a pre- and a postfossette are formed. In the third premolar, as in the second, a well-developed cingulum on the anterior side of the tooth is continuous with the internal cingulum. The antero-posterior and transverse dimensions of P$\underline{2}$ are nearly equal. This is true also for P$\underline{3}$, but the crown contracts more toward the inner side than in the preceding tooth. A pattern of the occlusal surface of P$\underline{3}$, similar to that in No. 1205, is seen also in No. 1222, but in specimen No. 1221 (Plate 2, fig. B), where this tooth is not so greatly worn, no union is established, at the stage of wear indicated, between the metaloph and posterior cingulum.

P$\underline{4}$ is compressed anteroposteriorly. A large anterior basin is formed on the crown of this tooth by union of protoloph and hypocone and by union of the latter cusp and metaconule. In view of the aspect of the crown shown in the illustration of the type specimen (Plate 1) it should be stated that the metaconule connects directly with the hypocone and not with the forward side of this cusp as might be implied from the figure. The characteristic type of union in *S. kewi* is illustrated also in the paratypes and can be clearly seen in No. 1221 (Plate 2, fig. B). A slender rib is developed on the outer wall of the forward basin and this is situated closer to the metaloph than to the protoloph.

Although an internal cingulum is lacking in M$\underline{1}$ this tooth possesses anterior and posterior cingula and a broad ledge between the obliquely transverse lophs. Toward the outer side the valley between these lophs is somewhat constricted. M$\underline{2}$ resembles the first molar in the development of the cingula. A slender rib on the inner wall of the ectoloph and situated close to the protoloph projects into the outer end of the median valley. Farther posteriorly on the ectoloph is a much stronger ridge or crest which also extends into the valley. The antero-external extension of the hypocone meets the posterior face of this crest near the point of union of the latter and the ectoloph. On the anterior surface of the posterior wall of $M\underline{3}$ are two longitudinal ribs. The rib toward the inner side is more strongly developed than the outer one.

The lower jaw, No. 1224, evidently of *Subhyracodon kewi* is shown in Plate 3, figure B. In this specimen the cheek-teeth are represented by $P\overline{2}$-$M\overline{3}$ and are considerably worn. No. 1224 possesses a relatively slender ramus, having a size comparable to that seen in some of the smaller species of the genus *Subhyracodon*. The symphyseal portion of the jaw, not shown in the illustration, is imperfectly preserved and the front teeth are missing. The alveolus for a lower tusk can be discerned on one side, but the wall is badly crushed. Measurements (in millimeters) of No. 1224 are: Length from anterior end of $P\overline{2}$ to posterior end of $M\overline{3}$, 156.6; depth of ramus behind $M\overline{3}$ (approximate), 65; height from inferior border to condyle (approximate), 157.

COMPARISONS

Comparison with White River and John Day Rhinoceroses

The upper tooth formula ($\underline{2}$, $\underline{1}$(0?), $\underline{4}$, $\underline{3}$) and the stage of evolution presented by the premolars in No. 1205 from the Sespe of the Las Posas Hills characterize a type less advanced than rhinoceroses generally grouped under the genus *Diceratherium*. The structural features seen in the Californian form are more like those found in the genus *Cænopus*. In recent years Wood[1] has come to recognize several divisions among the rhinoceroses heretofore grouped under the latter and places most of the American species of the later Oligocene within the genus *Subhyracodon*. Among the species included are *S. copei*, *S. trigonodum*, *S. occidentale* and *S. tridactylum*. Inappropriate though the name *Subhyracodon* may be, if we accept the restricted use of the genus *Cænopus* as advocated by Wood, the character of $P\underline{4}$ in the Californian form is certainly not that seen in *C. mitis* (Cope) but comes distinctly nearer that found in the former group of rhinoceroses.

No. 1205 is larger than the type of *S. copei*, coming nearer in size to *S. trigonodum* and to *S. occidentale*. The species *tridactylum* is larger than the Californian form.

Subhyracodon kewi resembles the species *trigonodum* and differs from *copei*, *occidentale* and *gidleyi* in the character of union of the hypocone and metaconule in $P\underline{4}$.

In the last named three species the metaconule joins the antero-external end of the hypocone, a character which Wood has pointed out distinguishes these forms from *S. trigonodum*. In *S. kewi* the union of the protoloph and metaloph tends to form a blunt V-shaped crest, and the hypocone does not form a hook-like projection behind the metaconule. In the union of the two cross-lophs, which takes place at an early stage of wear, *S. kewi* differs distinctly from *Subhyracodon metalophum* and *S. tridactylum.* In the latter forms the lophs are separate.

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[1] H. E. Wood 2d., Bull. Amer. Pale., vol. 13, No. 50, 1927.

Subhyracodon kewi differs particularly from *Amphicænopus platycephalus* in much smaller size and in the more progressive characters of the premolars. Both forms are hornless rhinoceroses of the later Oligocene.

In the absence of internal cingula on the molars of *S. kewi,* this form differs from *S. gidleyi* in which incomplete cingula are present. As in the latter, the Sespe specimens show a well-developed ledge or shelf between the lophs of M$\underline{1}$ and this may be raised at the inner end to form a low tubercle or ridge.

As in the referred specimen of *S. trigonodum,* No. 1131 A. M. N. H., mentioned by Wood, a slight posterior extension of the ectoloph in M$\underline{3}$ may occur in *S. kewi.*

In the presence of accessory ribs on the posterior premolar and molars, *S. kewi* is probably more advanced than *S. trigonodum.* In the presence of the upper canine, pattern of P$\underline{3}$ and P$\underline{4}$, absence of horn pedicles on nasals and smaller size, *S. kewi* appears to be distinctly less advanced than *S. tridactylum.*

Of the several types listed by Wood under the genus *Subhyracodon,* only *S. tridactylum* comes from the highest faunal horizon (Protoceras beds) of the White River. Although the Kew Quarry fauna of the Sespe in the Las Posas Hills may be broadly equivalent to or later than the Protoceras horizon, the rhinoceroses are evidently more primitive than those grouped under *Diceratherium* and differ also from *S. tridactylum.* Their nearest resemblance appears to be with *S. trigonodum,* while the resemblance with *copei, occidentale* and *gidleyi* is less marked.

In recent surveys of the John Day diceratheres by Troxell and by Wood the following species have come to be regarded as valid:

Diceratherium annectens (Marsh)
Diceratherium armatum (Marsh)
Diceratherium lobatum Troxell
Diceratherium cuspidatum Troxell

Troxell agrees with Peterson in placing *D. nanum* in a position subordinate to *armatum.* *D. hesperium* and *D. pacificum,* recognized by very fragmentary materials, are considered by Troxell and by Peterson as not adequately established in the John Day faunas.

In marked contrast to the resemblances or identity among mammalian genera found in the John Day and Kew Quarry faunas stands the dissimilarity of the rhinoceroses. It is possible that further acquisition of material from the John Day beds may demonstrate the presence of rhinoceroses currently grouped under the broad division

Cænopus. However, the extensive collections obtained from the John Day seem to have established the presence of diceratheres in the John Day fauna to the exclusion of the latter forms. On the other hand, the presence of peculiar conditions in the physical or biotic environment during the period of accumulation of the materials at the Kew Quarry site may account for the representation of one type and the apparent absence of diceratheres. At the present stage of our study of the Kew Quarry fauna it is certainly unsafe to say that the diceratheres were definitely excluded from this faunal horizon.

Comparison with Early Tertiary Rhinoceroses of the California Region

Two rhinoceroses from deposits evidently older than middle Tertiary are recorded for the Californian region. The materials obtained in Calaveras County during the Whitney Geological Survey were described by Leidy. The name *Rhinoceros hesperius* was proposed by Leidy[1] for the most complete specimen from Chili Gulch, a fragmentary lower jaw with dentition incompletely preserved, now in the collections of the Harvard Museum of Comparative Zoölogy. In a later statement[2] this jaw was again described and figured for the first time. Mention is made also of fragments of upper teeth and an unworn crown of an upper third molar from Calaveras County, which were regarded as probably belonging to *R. hesperius.* Still later, Whitney[3] quotes from Leidy a description of an additional specimen, a ramus with teeth of a young individual found at Douglas Flat. This likewise was regarded as probably of the species *R. hesperius.*

Subsequently the specimen figured by Leidy was mentioned by Osborn,[4] who referred the species to the genus *Aceratherium.* Meanwhile Leidy[5] had recorded rhinocerotid remains from the John Day basin and had determined some of this material as doubtfully of the species *R. hesperius.* In later years Loomis,[6] Peterson[7] and Troxell[8] have assigned this material either certainly or tentatively to the genus *Diceratherium,* although Peterson and Troxell regard the specimens as inadequate. Loomis has erred in regarding as type of the species *Diceratherium hesperius* the lower tooth from the John Day beds. While the lower jaw from Chili Gulch, Calaveras County, is, by inference, assigned to *Diceratherium,* definite generic determination still awaits a comparison with known representatives of this group in the John Day fauna.

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[1] J. Leidy, Proc. Acad. Nat. Sci. Phila., 176–177, 1865.
[2] J. Leidy, Jour. Acad. Nat. Sci. Phila., vol. 7, 2d ser., 230–232, pl. 23, figs. 11 and 12, 1869.
[3] J. D. Whitney, Mem. Mus. Comp. Zoöl. Harvard, vol. 6, 243–244, 1879.
[4] H. F. Osborn, Mem. Amer. Mus. Nat. Hist., vol. 1, pt. 3, 144–145, fig. 42, 1898.
[5] J. Leidy, Hayden Rpt. U. S. Geol. Surv. Terr., vol. 1, 220–221, pl. 2, figs. 8 and 9, 1873.
[6] F. B. Loomis, Amer. Jour. Sci., ser. 4, vol. 26, 55 and 56, fig. 5, 1908.
[7] O. A. Peterson, Mem. Carnegie Mus., vol. 7, 411, fig. 6, 1920.
[8] E. L. Troxell, Amer. Jour. Sci., ser. 5, vol. 2, 197 and 201, 1921.

The lower jaw of *Subhyracodon kewi* is more slender than that of *Diceratherium? hesperium* and the teeth are smaller with thinner enamel walls. The symphyseal region in the former species is likewise more slender and doubtless the lower tusks were not so robust as in the latter. The rhinoceros from Calaveras County was evidently a larger type and closely approached diceratheres from the John Day in size. However, there appears to be no evidence to indicate that *D.? hesperium* was not a large representative of the genus *Subhyracodon.* In the description of an unworn M$\underline{3}$, probably belonging to *D.? hesperium,* Leidy[1] calls attention to the presence of a prominent crest which projects forward from the posterior lobe into the transverse valley. As indicated in the description of the upper dentition of *S. kewi,* two ribs or crests project into this valley, but these structures are never so prominently developed as in Leidy's specimen or in specimens of diceratheres from the John Day.

Fragmentary teeth from the Tecuya beds of Tecuya Canyon were referred tentatively to *Cænopus* or *Diceratherium* by Stock.[2] Because of the incomplete preservation of the three teeth available, comparison with *Subhyracodon kewi* is unsatisfactory. The specimens from the Tecuya belong to an individual larger than those represented by the rhinoceroses from the Kew Quarry.

Miohippus sp.

A fragment of the left ramus, No. 461, Plate 4, represents a young individual in which Dp $\overline{2}$, Dp $\overline{3}$ and Dp $\overline{4}$ are present and only very slightly worn and M$\overline{1}$ is just appearing above the alveolar border. In front of Dp $\overline{2}$ is the alveolus and single root-fragment of Dp $\overline{1}$. No. 461 approximates closely in size a ramus with teeth of a slightly older yet immature individual of *Miohippus,* No. 7279 Amer. Mus., from the Diceratherium beds of the John Day. In the latter the deciduous premolars are more worn and M$\overline{1}$ and M$\overline{2}$ are in function but M$\overline{3}$ has not appeared. The dentition available in the form from the Sespe is more nearly like that in No. 7279 in size than like that in specimens of *Miohippus* (*Mesohippus*) *intermedius* with which comparisons are made. A large jaw with permanent teeth, No. 1193 Amer. Mus., referred provisionally to *Miohippus* (*Mesohippus*) *validus,* from the Protoceras beds of South Dakota, has a M$\overline{1}$ broader but not longer than in the Sespe type. This is a large species with only a very slight indication of separation of metaconid-metastylid column.

In specimen No. 461 an external cingulum is present at the base of the protoconid in Dp $\overline{3}$ and Dp $\overline{4}$, swinging outward from the base of the paraconid ridge. The ledge extends backward and bridges the notch between protoconid and hypoconid but is not present on the external side of the latter cusp. M$\overline{1}$ is not sufficiently exposed to show the nature of the external cingulum in this tooth. All of the teeth exhibit a posterior cingulum extending outward from the entostylid (hypoconulid). In character of cingulum No. 461 resembles *Miohippus,* No. 7279. The Sespe form is also like No. 679, Amer. Mus., a fragmentary ramus of *Miohippus* (*Mesohippus*) *intermedius* from the

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[1] J. Leidy, *ibid.*, 232, 1869.

[2] C. Stock, Univ. Calif. Publ. Bull. Dept. Geol., vol. 12, 271–272, figs. 4 and 5, 1920.

Comparative measurements (in millimeters)

	Subhyracodon kewi n.sp. Type, No. 1205 C.I.T.	*Subhyracodon kewi* n.sp. Paratype, No. 1221 C.I.T.	*Subhyracodon kewi* n.sp. Paratype, No. 1222 C.I.T.	*Subhyracodon trigonodum* Type, No. 528 A.M.N.H.	*Subhyracodon copei* Type, No. 522 A.M.N.H.	*Subhyracodon occidentale* Neotype, No. 114* U.S.N.M.	*Subhyracodon tridactylum*, No. 1122 A.M.N.H.	*Subhyracodon metalophum* Type, No. 1123 A.M.N.H.
Length from anterior end of P$\underline{1}$ to posterior end of M$\underline{3}$	*a*178.3	176.7	....	173.4	158.4	182	214.6	195.8
Length from anterior end of P$\underline{1}$ to posterior end of M$\underline{2}$	157.6	149	....	147.8	135.8	....	176.4	168.3
Length from anterior end of P$\underline{2}$ to posterior end of M$\underline{2}$	141.3	136.3	....	133	120.2	....	162.7	149.9
Length of premolar series, through middle	86.1	79.2	....	80.3	76	....	98.2	93
Length of molar series, through middle	....	99.8	99.2	95.2	83.6	....	112	104.3
P$\underline{1}$, anteroposterior diameter	17.9	18	....	16.8	17.2	*a*19	20.1	20.6
P$\underline{1}$, greatest transverse diameter	15.8	17.5	....	16.7	16.3	....	19.8	20.9
P$\underline{2}$, greatest anteroposterior diameter	22.6	23	21	20.8	20.4	20.5	28.2	24.2
P$\underline{2}$, greatest transverse diameter	23.8	23.3	22	24.1	25.2	26	35.2	31.1
P$\underline{3}$, greatest anteroposterior diameter	28.2	26.5	23.5	24.2	21.8	22.3	29.8	27.8
P$\underline{3}$, greatest transverse diameter	28.1	29.2	28.6	31.3	29	34.1	40.8	37.3
P$\underline{4}$, greatest anteroposterior diameter	28.3	26.9	26	24.7	23.7	23.5	33.4	29.5
P$\underline{4}$, greatest transverse diameter	32.2	33.3	32.7	33.7	31.7	37	45.4	40.7
M$\underline{1}$, greatest anteroposterior diameter	36.2	36.1	30.5	35.3	31.1	30.5	40.1	40
M$\underline{1}$, greatest transverse diameter	34.8	38	34.4	35.2	32.8	38.8	45.2	40.1
M$\underline{2}$, greatest anteroposterior diameter	41.8	42.7	38.4	38.2	34.3	34.6	45.3	42.5
M$\underline{2}$, greatest transverse diameter	36.3	40.4	39	37.4	35.5	41.5	46.4	43.7
M$\underline{3}$, greatest anteroposterior diameter parallel to inner side	....	35.4	35.2	30.7	29	....	38.3	35.8
M$\underline{3}$, greatest transverse diameter	....	40.1	35.1	39.1	34.1	....	42.1	40.4

* Measurements after Wood. *a*, Approximate.

Protoceras beds of the White River, South Dakota, and like specimens (No. 676 Amer. Mus.) referred to *Mesohippus bairdii* from the White River.

M$\overline{1}$ has a crown height similar to that in *Miohippus* from the John Day. The crown height is slightly greater in these forms than in *M. intermedius* from the Protoceras beds.

In Dp $\overline{3}$ and Dp $\overline{4}$ the metaconid and metastylid are distinct and the cleft separating the two cusps extends for a short distance below the occlusal surface. Likewise, a separation of the two cusps is evident in M$\overline{1}$. This character occurs also in *Miohippus* from the John Day, in *M. intermedius* of the White River, and is slightly less marked in *Mesohippus bairdii* from the Oreodon beds of South Dakota (No. 676 Amer. Mus.). In the permanent teeth of an adult individual of *Miohippus intermedius* (No. 681 Amer. Mus. from the Protoceras beds) no separation of the metaconid-metastylid column is evident, while in the permanent teeth of *M.* cf. *equiceps* (Cope) from the John Day (No. 7287 Amer. Mus.) a definite indication of separation is shown although much less marked than in No. 7279 from the John Day. In permanent teeth of *Mesohippus bairdii* the division is usually absent, although it may be feebly developed in some specimens, as for example in No. 8794 Amer. Mus., a lower jaw referred to this species and collected in the Oreodon beds of Cedar Creek, Colorado.

The entostylid becomes progressively larger in the posterior deciduous teeth. In M$\overline{1}$ it approximates in size or may be slightly smaller than that in Dp$\overline{4}$.

Dp$\overline{1}$ appears to have been a small tooth, in size more nearly like that in *M. intermedius* than like that in *Miohippus* (No. 7279 Amer. Mus.) from the John Day.

Dp$\overline{2}$ is particularly interesting because of the characters exhibited at the anterior end. In size and anteroposterior elongation this tooth in No. 461 is more like that in No. 7279 than like that in Nos. 682 and 679 referred to *M. intermedius* from the White River.

In Dp$\overline{2}$ of the Sespe species, as in the comparable tooth of *Mesohippus* from the White River and of *Miohippus* from the John Day, the cusps of the posterior half of the tooth are closely similar to those on the remaining deciduous teeth and on the permanent molar. The forward portion of this tooth is, however, quite differently constructed and consists of two cusps, one anterior (paraconid) and one postero-external (protoconid). From the latter cusp extend crests in three directions, namely (1) forward to the paraconid, (2) postero-internal toward the metaconid, and (3) postero-external to the ledge in front of the hypoconid. The median valley of the external side is deep and has a characteristic oblique direction. Essentially the same characters are found in the forward portion of Dp$\overline{2}$ of *Mesohippus*. In P$\overline{2}$ of *Mesohippus* and *Miohippus* no distinct metastylid is present but the postero-internal crest from the protoconid extends in front of the inner end of the antero-internal crest from the hypoconid. In both *Mesohippus* and *Miohippus* the postero-external crest from the protoconid is a striking feature of both Dp$\overline{2}$ and P$\overline{2}$, distinguishing these genera from the later anchitheriine horses.

In a specimen of *Archæohippus* from the Sheep Creek beds, Nebraska, No. 21532 Amer. Mus., slightly smaller than No. 461 from the Sespe but with the deciduous premolars somewhat more worn than in the latter, Dp$\overline{2}$ is more advanced than the comparable tooth in No. 461. In this tooth a postero-internal crest from the protoconid is well developed and terminates in a distinct metaconid. The notch between the paraconid and metaconid is likewise more deeply incised in *Archæohippus* than in *Miohippus.* No. 21532 possesses relatively higher crowned teeth than No. 461.

Essentially the same differences in Dp$\overline{2}$ prevail between the *Miohippus* specimen from the Sespe and *Parahippus,* near *cognatus,* No. 14305 Amer. Mus. from the Miocene near Marsland, Nebraska. There is apparently less difference in the arrangement of crests and cusps between Dp$\overline{2}$ and P$\overline{2}$ in *Parahippus* than in *Miohippus.*

In the deciduous premolars of *Hypohippus osborni,* No. 8256 Amer. Mus. from the Pawnee Creek beds of Colorado an external cingulum may be present not only along the base of the protoconid but also along the base of the hypoconid. These teeth are moderately worn in No. 8256. Unfortunately the tips of the metaconid-metastylid columns are broken in Dp$\overline{3}$ and Dp$\overline{4}$. In Dp$\overline{2}$ at this stage of wear there is no indication of an indentation of the inner wall to separate metaconid from metastylid. A slight separation of the two cusps is evident in M$\overline{2}$, but is limited to the tip. In view of the size of the teeth in *Hypohippus* the separation of the metaconid and metastylid appears to be less progressive than in *Miohippus.* In *Hypohippus* the enamel patterns of Dp$\overline{2}$ and P$\overline{2}$ are similar, in which respect this genus is like *Archæohippus* and *Parahippus.* In the second deciduous premolar and in the permanent second premolar of *Archæohippus, Parahippus* and *Hypohippus* the more external position of the protoconid lessens in these forms the prominence of the postero-external ridge, in which respect these genera can be distinguished from *Mesohippus* and *Miohippus.*

The jaw from the Sespe evidently represents a type more advanced than typical *Mesohippus,* yet this form has not reached the stage of development represented by *Archæohippus* or by *Parahippus cognatus.* The characters displayed by the teeth are clearly those typically developed in *Miohippus.* A comparison with jaws of various species of *Miohippus* from the Protoceras beds of the White River and from the John Day indicates considerable similarity on the part of No. 461. From specimens referred to *M. intermedius* and questionably to *M. validus,* No. 461 differs in size of cheek-teeth or in the more pronounced separation of the metaconid and metastylid, or in both characters. In hypsodonty, particularly as expressed in M$\overline{1}$, the Sespe specimen appears to resemble more closely types from the John Day (*M.* cf. *equiceps,* No. 7287 Amer. Mus.). Excluding the large miohippine type, *Kalobatippus præstans* (Cope), known from the Upper John Day, no less than nine species have been described from the John Day deposits. Doubtless a revision of the latter forms would decrease the number of valid species. It would serve no particular purpose in view of the present incomplete material from the Sespe to attempt at this time a determination of the relationships with the various species recorded from the John Day.

SUMMARY

Perissodactyla in the Kew Quarry fauna from the Las Posas Hills, California, are represented by rhinoceroses of a new species for which the name *Subhyracodon kewi* is proposed, and by a horse of the genus *Miohippus.* In this late Oligocene assemblage the rhinoceroses were evidently more numerous than were the horses.

Subhyracodon kewi is more closely related to species found in the White River of the western Great Plains than to the diceratheres of the

John Day. On the basis of the characters displayed by the material available, the horse from the Sespe is closely related to species of *Miohippus* occurring in the John Day fauna.

Comparative measurements of Anchitheriine species (in millimeters)

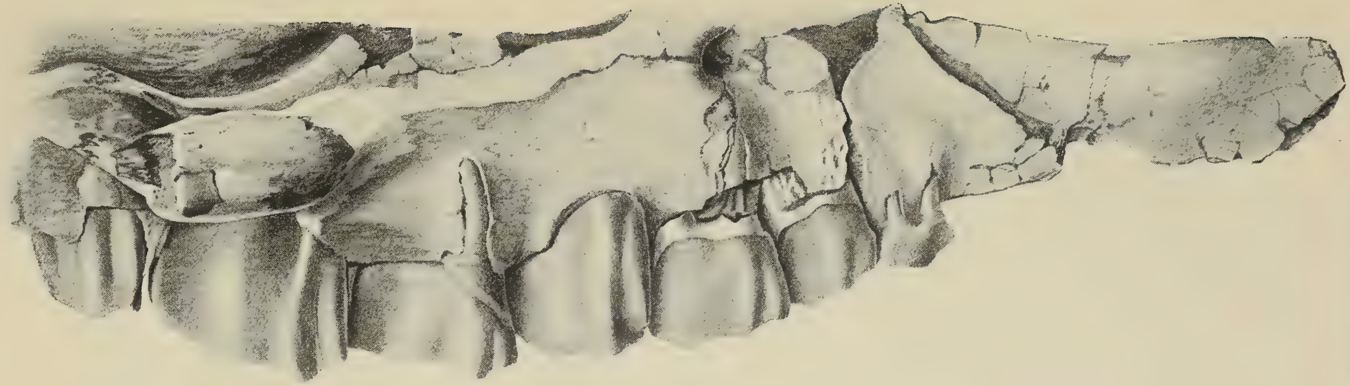
	Miohippus sp. No. 461 C.I.T. Sespe	*Mesohippus bairdii* No. 676 A.M.N.H.	*Miohippus intermedius* No. 679 A.M.N.H.	*Miohippus intermedius* No. 682 A.M.N.H.	*Miohippus* sp. No. 7279 A.M.N.H.	*Archæohippus penultimus* No. 21532 A.M.N.H.	*Parahippus* cf. *cognatus* No. 14305 A.M.N.H.
Length from anterior end of Dp$\overline{2}$ to posterior end of Dp$\overline{4}$..........	48.4	35.3	38.5	44.0	47.2	44.5	59.9
Dp$\overline{2}$, anteroposterior diameter.	17.0	12.3	13.5	15.1	17.0	16.4	21.1
Dp$\overline{2}$, transverse diameter across hypoconid.....	8.9	7.4	8.1	8.5	9.7	8.4	11.5
Dp$\overline{3}$, anteroposterior diameter.	16.0	11.8	13.1	14.8	15.5	13.7	19.0
Dp$\overline{3}$, transverse diameter across hypoconid.....	10.2	8.9	8.9	9.6	10.5	8.7	12.1
Dp$\overline{4}$, anteroposterior diameter.	16.5	12.0	12.6	14.6	14.8	14.1	19.9
Dp$\overline{4}$, transverse diameter across hypoconid.....	10.3	8.5	8.7	*a*9.4	10.3	8.7	11.6

a, Approximate.

Plate 1

Subhyracodon kewi n. sp.

Type, No. 1205 Calif. Inst. Tech. Coll., lateral and inferior views; x 2/3. J. L. Ridgway, del.
Sespe Oligocene, Las Posas Hills, California.



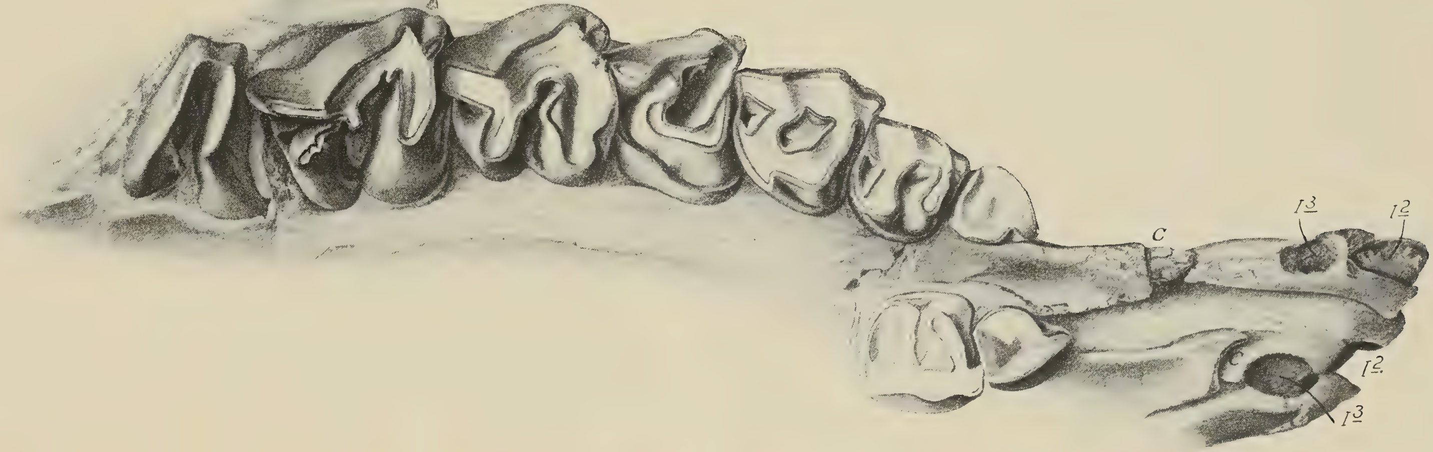

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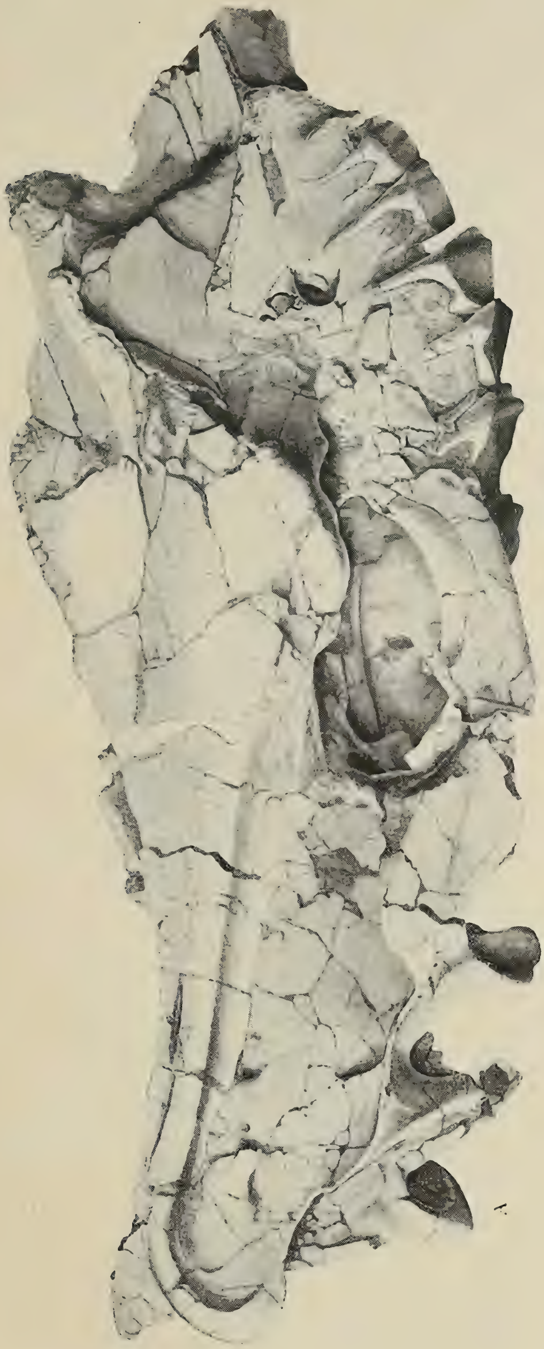
PLATE 2

Subhyracodon kewi n. sp.

A. Paratype, No. 1222, skull viewed from side and top.
B. Paratype, No 1221, skull in ventral view.
All figures, x 2/5 J. L. Ridgway, del. Calif. Inst. Tech. Coll. Sespe Oligocene, Las Posas Hills, California.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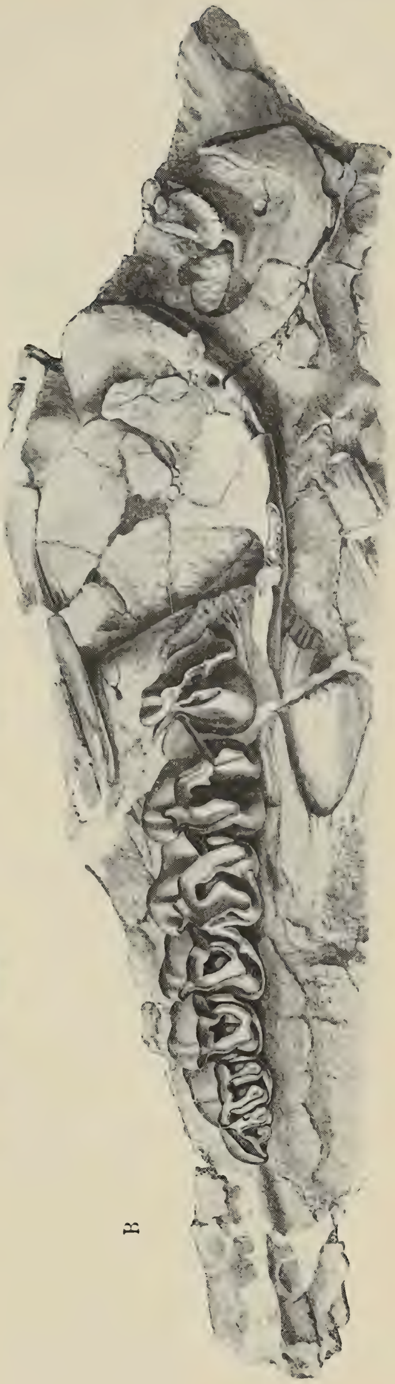

B

PLATE 3

Subhyracodon kewi n. sp.

A. Skull, No. 1222, view of occiput.
B. Mandible, No. 1224, lateral view.
C and D. Right premaxillary with incisor, No. 1225; C, lateral view; D, ventral view.
All figures, x 1/2. J. L. Ridgway, del. Calif. Inst. Tech. Coll. Sespe Oligocene, Las Posas Hills, California.

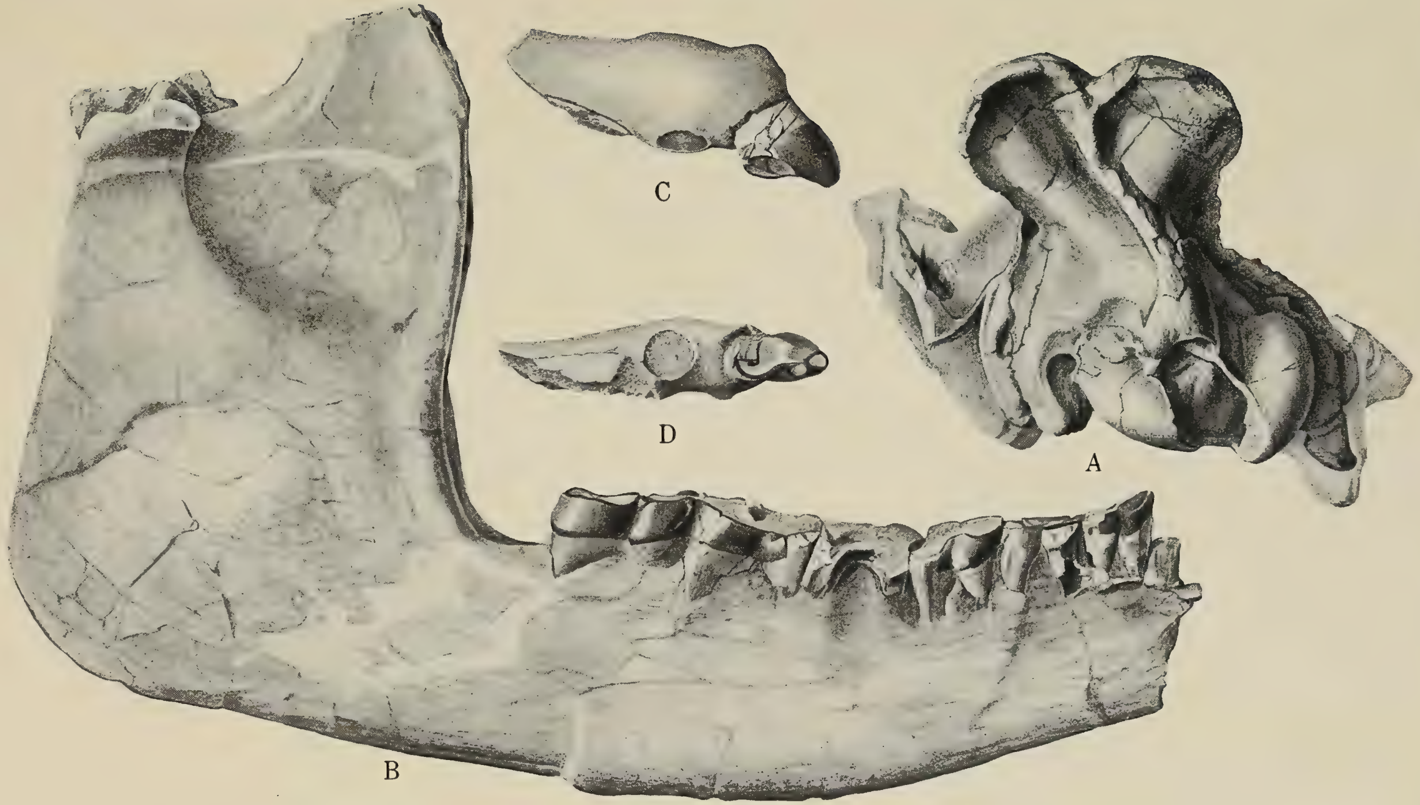
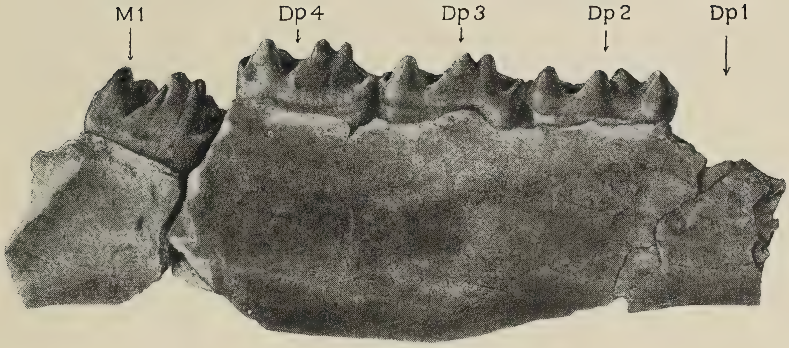

C
A
D
B

Plate 4

Miohippus sp.

A to C. Fragment of left ramus with $\mathrm{Dp}\bar{2}$-$\mathrm{Dp}\bar{4}$, $\mathrm{M}\bar{1}$, No. 461 Calif. Inst. Tech. Coll. A, inner view; B, occlusal view; C, lateral view; x 1 1/5. Sespe Oligocene, Las Posas Hills, California.



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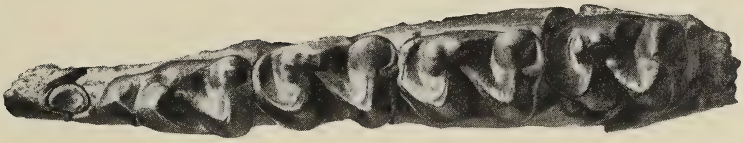

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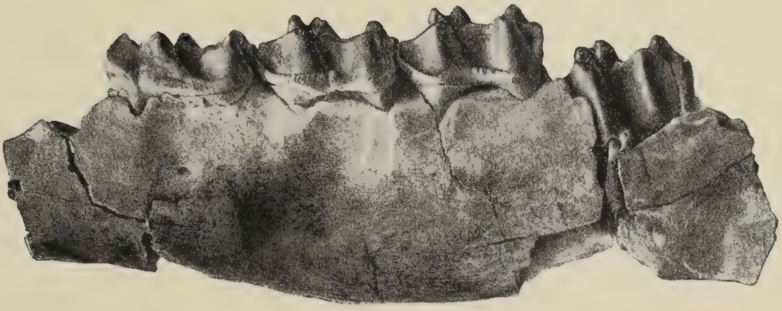

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CARNIVORA FROM THE SESPE OF THE LAS POSAS HILLS, CALIFORNIA

By Chester Stock

With three plates

[Issued November 1933]

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CARNIVORA FROM THE SESPE OF THE LAS POSAS HILLS, CALIFORNIA

INTRODUCTION

The generic assemblage of carnivores known at present from the Kew Quarry of the Las Posas Hills, Ventura County, California, is perhaps most noteworthy because of its resemblance to that recorded from the John Day. Three members of the Canidæ and two of the Felidæ have been listed[1] on the basis of skull remains. More detailed investigation of the structural characters of these types reveals a close specific similarity to comparable forms from the John Day. Indeed, one of the principal reasons for regarding the fauna from the Kew Quarry as closely related in time to that from the John Day beds of eastern Oregon is furnished by this kinship among the Carnivora.

Although all of the carnivores are new to the Tertiary mammalian faunas of the Californian region, the skull material of *Hoplophoneus* possesses added interest, representing as it does the smallest sabre-tooth cat from North America. Surprising, to say the least, is this striking evidence that within the Tertiary faunal province of southern California occurred an early member of that great group of cats, of which one of the latest and most advanced stages of development is recorded so fully in the Pleistocene *Smilodon* of the asphalt deposits of Rancho La Brea.

Pseudocynodictis(?) pavidus n. sp.

Type specimen—A crushed skull and mandible with dentition, excepting incisors, No. 466 Calif. Inst. Tech. Coll. Vert. Pale., Plate I, figs. 1–5. Collected at Locality 126.

Specific characters—Very small size. No. 466 from the Sespe is smaller than *Cynodictis gregarius*, *C. lippincottianus* and *C. paterculus* from the Oreodon and Titanotherium beds of the White River and is distinctly smaller than *Cynodictis*(?) *oregonensis* from the John Day. $P\overline{2}$ lacks posterior cusp. $M\underline{2}$ relatively large.

Description—This very small canid is evidently more closely related to forms that have been grouped under the genus *Cynodictis* than to representatives of the genus *Nothocyon*. No. 466 is smaller than *Nothocyon lemur* and in absence of the nothocyonid characters of $M\overline{1}$ resembles *Cynodictis*. Likewise, it differs from *Nothocyon* and resembles the latter genus in the transverse extension of the upper molars. Osborn[2] has recently noted that it may be necessary to distinguish the small cynodictid species of the North American middle and lower Oligocene by the name *Pseudocynodictis* (Schlosser). For want of more definite information regarding the generic relationships of the Sespe species, other than that it can be excluded from the genus *Nothocyon*, as this group is now interpreted in the John Day fauna, the former is assigned tentatively to *Pseudocynodictis*.

[1] C. Stock, Proc. Nat. Acad. Sci., vol. 18, 550–554, 1932.

[2] H. F. Osborn, U. S. Geol. Surv. Monograph 55, vol. 1, 118, 1931.

The characters of the dentition recognized by Merriam and Matthew[1] as distinguishing the John Day species *Cynodictis*(?) *oregonensis* from *C. gregarius* are (1) constant presence of a posterior cusp in addition to the anterior and posterior basal tubercles on P$\overline{2}$, (2) larger M$\underline{2}$, (3) slightly smaller size of premolars and carnassials, (4) more quadrate internal side of M$\underline{1}$, with a farther forward extension of hypocone crescent around protocone, and (5) much larger size of M$\overline{2}$.

No. 466 lacks the posterior cusp in P$\overline{2}$ but possesses a relatively large M$\underline{2}$. However, the former character may not possess special significance in view of the fact that Thorpe[2] has found the presence or absence of an additional cusp in P$\overline{2}$ subject to individual variation within species of the genus *Cynodictis*. The premolars and carnassials are small. In character of M$\underline{1}$, the Sespe form probably resembles *C. gregarius* more than it does *C. oregonensis*. Likewise, M$\overline{2}$ appears more nearly comparable in size to that in the White River form. In this tooth the portion anterior to the protoconid and metaconid is shortened slightly and the paraconid ridge has the appearance of being appressed slightly more than in the former two species.

The right lower canine is shown in Plate I, figure 5. The surface of the crown of this tooth is marked by longitudinal wrinkles.

Measurements of No. 466 C.I.T. (in millimeters)

P$\underline{4}$, anteroposterior diameter	6.0
P$\underline{4}$, transverse diameter across protocone	3.8
M$\underline{1}$, anteroposterior diameter taken parallel to outer side	4.9
M$\underline{1}$, greatest transverse diameter taken normal to outer side	6.3
M$\underline{2}$, anteroposterior diameter taken parallel to outer side	3.0
M$\underline{2}$, greatest transverse diameter taken normal to outer side	4.7
Length from anterior end of P$\overline{1}$ to posterior end of M$\overline{2}$	24.6
$\overline{\mathrm{C}}$, anteroposterior diameter at base of enamel	2.6
P$\overline{1}$, anteroposterior diameter	1.7
P$\overline{2}$, anteroposterior diameter	3.4
P$\overline{3}$, anteroposterior diameter	4.2
P$\overline{4}$, anteroposterior diameter	4.8
M$\overline{1}$, anteroposterior diameter	6.8
M$\overline{1}$, transverse diameter across heel	3.0
M$\overline{2}$, anteroposterior diameter	3.9
M$\overline{2}$, greatest transverse diameter	2.8

Mesocyon baileyi n. sp.

Type specimen—A crushed skull with mandible and most of the dentition, No. 471 Calif. Inst. Tech. Coll. Vert. Pale., Plate II, figs. 1–3. Collected at Locality 126, Las Posas Hills, Ventura County, Calif. This species is named in honor of Dr. Thomas L. Bailey.

Referred specimen—A right skull fragment with C, P$\underline{1}$–M$\underline{2}$, No. 1242 Calif. Inst. Tech. Coll. Vert. Pale., Plate I, figs. 7 and 8. In the collections are also several rami, including Nos. 467 and 1346.

Specific characters—More nearly like *Mesocyon brachyops* and *M. josephi* in size than like *M. coryphæus*. Differs from type of *M. josephi* in larger molars, smaller and more crowded anterior premolars, and in presence of posterior cusp in P$\underline{3}$. M$\underline{1}$ in *M. baileyi* shorter transversely than comparable tooth in *M. brachyops*. Hypocone crest prominent and curving more decidedly to the postero-internal side than in M$\underline{1}$ of *M. brachyops*.

Description—Individuals of the genus *Mesocyon* are of relatively frequent occurrence in the fauna from the Kew Quarry. The number of specimens referable to this canid type exceeds that of any other carnivore recorded in the collections from Locality 126. It is interesting to note that among the Canidæ of the John Day, *Mesocyon* is likewise a relatively common form.

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[1] J. C. Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, 11, 1906.

[2] M. R. Thorpe, Amer. Jour. Sci. ser. 5, vol. 3, 163, 1922.

In the crowding of the premolars and in the small space occupied by P$\underline{1}$, No. 471 resembles *M. brachyops*. While the facial region in the Sespe species appears comparable in length to that in *M. josephi*, the molar teeth are absolutely larger than in the latter type, while the anterior premolars are smaller and more crowded. P$\underline{3}$ has a posterior cusp and basal tubercle as in *M. coryphæus* and in *M. brachyops*. The posterior cusp is lacking in the type of *M. josephi*. M$\underline{1}$ is intermediate in size between *M. josephi* and *M. coryphæus*. M$\underline{2}$ is relatively and absolutely larger in No. 471 than in No. 6859 Amer. Mus., the type of *M. coryphæus*. This tooth is, however, more nearly comparable in size to that in *Mesocyon* than to that in *Paradaphænus*.

In the type of *Mesocyon brachyops* the transverse extension of M$\underline{1}$ is greater although the anteroposterior diameter in the region of the protocone is less than in No. 471 from the Sespe. The inner portion of the crown in this tooth is worn in the type of *M. brachyops*, but the hypocone crescent does not swing to the postero-internal side so noticeably as in *M. baileyi*. The latter character is shown particularly well in No. 1242 from the Kew Quarry (see Plate I, fig. 8). In *M. brachyops* the cingulum at the antero-external corner of the first molar is more strongly developed than in *M. baileyi*. Moreover, in the former the outer wall of M$\underline{1}$ slopes decidedly inward in its backward course, and the intersection of a line drawn parallel to the edge of this wall and a line drawn parallel to the outer edge of P$\underline{4}$ gives a smaller inner angle than in *M. baileyi*.

While the crushing of the skull in No. 471 has shattered the basicranial region, the amount of telescoping in fore and aft direction of the cranium does not appear to account entirely for the difference in distance between postglenoid process and occipital condyle which exists between this type and *M. brachyops*. It appears at least possible that in the Sespe species the basicranial region was shorter and the otic bullæ not so large as in *M. brachyops*.

The occipital crests in No. 471 are well developed. Between these and the median crest above the foramen magnum are deep indentations which extend well up toward the dorsal border of the occiput. The sagittal crest was apparently also well defined, but relatively no more so than in *M. coryphæus*.

Measurements of the inferior dentition in No. 471 indicate a size slightly smaller than that of No. 1307 Univ. Calif., a specimen from the John Day referred by Merriam to *M. coryphæus*. Additional specimens from the John Day indicate, according to Merriam, considerable variation in size among members of the *coryphæus* group.

The anterior basal tubercle in P$\overline{2}$ and P$\overline{3}$ is minute. A posterior cusp is absent in these teeth. Merriam, in the description of a mandible (No. 364 Univ. Calif.) referred provisionally to *Mesocyon josephi*, remarks that P$\overline{2}$ possesses a well-developed posterior cusp in addition to the anterior and posterior basal tubercles.

The lower jaw of No. 471 resembles in size that of *Mesocyon robustus*, No. 12884 Amer. Mus. from the Lower Rosebud. In the former specimen, however, P$\overline{1}$ is more reduced, the anterior premolars less spaced apart, and the molar series furnishes a greater crushing surface. P$\overline{4}$ has a posterior cusp and a basal ledge. In M$\overline{1}$ of No. 471 the inner posterior corner of the heel is more angulate than in *M. robustus*. M$\overline{2}$ and M$\overline{3}$ are larger than in the type from the Lower Rosebud.

Comparative measurements of skull and superior dentition (in millimeters)

	Mesocyon baileyi n.sp. Type No. 471 C.I.T. Sespe	*Mesocyon baileyi* n.sp. No. 1242 C.I.T. Sespe	*Mesocyon brachyops* Type No. 1692 U.C.C. John Day	*Mesocyon josephi* Type No. 6878 Amer. Mus. John Day	*Mesocyon coryphæus* Type No. 6859 Amer. Mus. John Day	*Mesocyon* sp. No. 7916 U.S.N.M. John Day	*Mesocyon iamonensis* Type No. 8836 U.S.N.M. Florida
Length from anterior end of premaxillary to posterior end of occipital condyle	*a*121.5	....	*a*134.8	....	158.2	150.4	....
Length from anterior end of premaxillary to inion	*a*125.5	....	....	....	164.6	....	....
Length from anterior end of C to posterior end of M$\underline{2}$	56.8	61.4	....	59.2	65.5	62.6	....
Length from anterior end of C to posterior end of M$\underline{1}$	52.2	58.9	*a*49.5	55.7	61.7	58.3	....
Length from anterior end of P$\underline{1}$ to posterior end of P$\underline{4}$	34.0	34.7	36.8	37.4	42.2	*a*37.5	....
C, anteroposterior diameter at base of enamel	*a*9.3	7.4	....	7.9	9.5	....	....
C, transverse diameter at base of enamel	....	5.2	....	6.0	6.7	....	....
P$\underline{1}$, anteroposterior diameter	*a*3.1	4.0	4.2	4.3	4.7	....	....
P$\underline{2}$, anteroposterior diameter	8.1	7.3	6.8	8.2	8.4	....	....
P$\underline{2}$, greatest transverse diameter	3.6	3.6	3.3	3.6	4.0	....	....
P$\underline{3}$, anteroposterior diameter	8.6	8.3	8.6	9.1	9.7	9.4	....
P$\underline{3}$, greatest transverse diameter	4.4	4.4	4.0	4.7	5.0	4.0	....
P$\underline{4}$, anteroposterior diameter	13.6	13.6	14.2	12.5	15.1	13.0	18.4
P$\underline{4}$, greatest transverse diameter across protocone	8.3	8.2	8.2	7.5	9.5	7.9	9.9
M$\underline{1}$, greatest anteroposterior diameter measured parallel to outer side	9.6	10.2	9.8	9.0	10.7	10.4	12.0
M$\underline{1}$, transverse diameter measured normal to outer side	11.9	11.5	12.1	10.7	12.8	12.0	15.0
M$\underline{1}$, anteroposterior diameter of inner heel across protocone	6.9	6.7	6.4	5.7	7.3	6.0	8.1
M$\underline{2}$, greatest anteroposterior diameter measured parallel to outer side	5.5	5.0	....	5.0	5.4	5.5	6.4
M$\underline{2}$, transverse diameter measured normal to outer side	7.3	7.4	....	6.8	7.0	8.3	9.7
M$\underline{2}$, anteroposterior diameter of inner heel across protocone	4.8	4.5	....	4.0	4.2	4.3	5.2

a, Approximate.

Comparative measurements of mandible and inferior dentition (in millimeters)

	Mesocyon baileyi n.sp. Type No. 471 C.I.T. Sespe	*Mesocyon coryphæus* No. 1307 U.C.C. John Day	*Mesocyon* sp. No. 7916 U.S.N.M. John Day	*Mesocyon robustus* No. 12884 Amer. Mus. L. Rosebud
Depth of jaw at front end of P$\overline{3}$ measured normal to inferior border	16.4	*a*16.4	17.0	....
Depth of jaw at posterior end of M$\overline{1}$ measured normal to inferior border	17.7	*a*18.0	18.4	17.1
Length from anterior end of $\overline{C}$ to posterior end of M$\overline{3}$	64.4	*a*77.5	*a*68.0	69.9
Length from anterior end of P$\overline{1}$ to posterior end of M$\overline{3}$	54.4	....	56.0	57.4
I$\overline{3}$, transverse diameter	3.2	....	....	....
C, anteroposterior diameter at base of enamel	7.7	8.3	7.9	8.9
C, transverse diameter at base of enamel	*a*5.5	5.5	5.4	6.8
P$\overline{1}$, anteroposterior diameter	3.2	....	3.9	4.0
P$\overline{2}$, anteroposterior diameter	7.3	*a*9.0	7.8	7.5
P$\overline{2}$, greatest transverse diameter	3.6	3.5	3.5	3.6
P$\overline{3}$, anteroposterior diameter	8.4	9.4	9.1	8.1
P$\overline{3}$, greatest transverse diameter	....	4.0	4.0	4.1
P$\overline{4}$, anteroposterior diameter	9.9	10.0	10.4	9.1
P$\overline{4}$, greatest transverse diameter	....	4.6	4.5	4.4
M$\overline{1}$, anteroposterior diameter	14.2	16.5	15.6	14.7
M$\overline{1}$, greatest transverse diameter of heel	5.8	5.7	*a*5.2	5.0
M$\overline{2}$, anteroposterior diameter	6.8	....	6.8	6.4
M$\overline{2}$, greatest transverse diameter	4.9	....	5.1	4.4
M$\overline{3}$, anteroposterior diameter	4.6	....	....	3.6
M$\overline{3}$, greatest transverse diameter	3.5	....	....	2.7

a, Approximate.

Temnocyon cf. altigenis Cope

Referred specimen—A fragmentary right ramus with canine, P$\overline{3}$–M$\overline{2}$, No. 470 Calif. Inst. Tech. Coll. Vert. Pale., Plate I, fig. 6. Collected at Locality 126.

Description—The dentition in No. 470 is unfortunately rather poorly preserved. The cheek-teeth clearly exhibit, however, the distinguishing characters of *Temnocyon.* The crown of the canine is relatively slender. P$\overline{1}$ is absent. This tooth is present in *T. altigenis,* although not always preserved. Cope has remarked its presence in at least one jaw referred to this species. Evidently in two other specimens the anterior end of the ramus is imperfectly preserved. Merriam described the crown of this tooth in No. 9999 Univ. Calif. from the John Day, a skull and mandible referred to *T. altigenis.* Eyerman, however, in the description of *Temnocyon ferox* states that this tooth is missing, although the impression is given that the first premolar is not preserved. Dr. W. J. Sinclair has kindly examined this specimen for me and notes:[1]

"The front of the lower jaw is crushed, especially on right side, but on the left side there is the root of a single-rooted tooth measuring 6.5 mm. x 5 mm. immediately in front of P$\overline{2}$ and slightly displaced (*i. e.* out of line) toward the inner side of the jaw. 6 mm. in front of this root is the base of the canine."

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[1] Letter of October 25, 1932.

Absence of P$\overline{1}$ in the specimen from the Sespe may imply a greater shortening of the face in this species than in the types from the John Day. The diastema between the canine and the anterior root of P$\overline{2}$ is short, decidedly more so than in *T. ferox.*

The alveoli for P$\overline{2}$ indicate that of the two diverging fangs for this tooth, the posterior was distinctly larger than the anterior.

P$\overline{3}$, like the comparable tooth in *T. altigenis,* has a high median cusp without anterior and posterior basal cusps. P$\overline{4}$ is shorter in anteroposterior diameter than M$\overline{1}$. On the crown of this tooth is a prominent cusp situated on the outer posterior side of the principal cusp. There was also presumably an incipient basal tubercle, but the greater portion of the outer posterior corner of the crown is broken away. In the characters displayed by these teeth No. 470 makes a closer approach to *T. altigenis* than to *T. ferox.* The principal cusp in both P$\overline{3}$ and P$\overline{4}$ tends to lean or curve toward the inner side. This tendency is perhaps better expressed in P$\overline{4}$ than in P$\overline{3}$, because of the larger size of the tooth. The attitude of the cusp appears to be a distinguishing feature of *Temnocyon.*

Comparative measurements (in millimeters)

	Temnocyon cf. altigenis No. 470 C.I.T. Sespe	*Temnocyon altigenis* Type No. 6855 Amer.Mus. John Day	*Temnocyon altigenis* No. 9999† U.C.C. John Day	*Temnocyon ferox* Type Prin. Univ. John Day	*Temnocyon* large sp. No. 480 C.I.T. John Day
Length from anterior end of P$\overline{3}$ to posterior end of M$\overline{2}$	*a*57.7	56.4	...	73.0	...
C, anteroposterior diameter at base of enamel	14.1	...	...	18.2	...
C, transverse diameter at base of enamel	9.4	...	...	...	...
P$\overline{2}$, anteroposterior diameter, alveolar measurement	11.8	*11.0	*10.0	14.5	...
P$\overline{3}$, greatest anteroposterior diameter	14.0	12.6	11.7	*a*16.4	...
P$\overline{3}$, greatest transverse diameter	7.0	5.4	...	*a*7.2	...
P$\overline{4}$, greatest anteroposterior diameter	15.6	15.3	14.5	19.0	22.3
P$\overline{4}$, greatest transverse diameter	*a*7.5	6.9	...	8.3	9.8
M$\overline{1}$, greatest anteroposterior diameter	*a*20.0	17.7	17.3	21.4	28.1
M$\overline{1}$, transverse diameter of heel	9.8	9.0	...	10.4	11.6
M$\overline{2}$, greatest anteroposterior diameter	*a*11.0	11.2	10.3	12.6	15.3
M$\overline{2}$, transverse diameter of anterior half	7.1	6.6	...	7.9	9.5

*Measurement of tooth crown.

†Measurements in part after J. C. Merriam.

a, Approximate.

In M$\overline{1}$ the paraconid-protoconid blade is heavy and the shear is oblique. A well-worn metaconid is clearly shown. The heel is broad and supports a single large cusp (hypoconid) as in *Temnocyon.* The heel is probably no wider, relative to the length of the tooth than in the John Day species, but the postero-internal and postero-external corners are more angulate, giving a fuller appearance to this portion of the crown than in *T. altigenis.* A cingulum is evident along the outer side of the heel and is shown also for a short distance along the base of the oblique shearing face.

$M\overline{2}$ is well worn and exhibits in addition an abrasion which truncates the outer posterior angle of the crown. The arrangement of the cusps appears to have been similar to that in *Temnocyon.* $M\overline{2}$ is wider in front than the comparable tooth in *T. altigenis.* The posterior root is widely divergent.

As in the type of *T. altigenis,* moderately large mental foramina are present, one situated beneath the middle of $P\overline{3}$, the other below the anterior root of $P\overline{2}$.

Hoplophoneus belli n. sp.

Type specimen—A crushed skull, No. 463 Calif. Inst. Tech. Coll. Vert. Pale., Plate III, figs. 2 and 3, from locality 126, Las Posas Hills, Ventura County, California. This species is named in honor of my distinguished colleague, Professor E. T. Bell, in appreciation of his great love for cats.

Specific characters—Size approximating that of *Hoplophoneus cerebralis* Cope from the John Day, but smaller. Superior canine distinctly more slender than in *H. cerebralis* or in *H. oreodontis.*

Description—The individual represented by No. 463 had not attained full maturity as indicated by the incomplete emergence of the superior canine. The permanent cheek-tooth dentition is, however, present and the crowns of the posterior teeth ($P\underline{4}$ and $M\underline{1}$) are distinctly worn. In the presence of permanent cheek-teeth and of the partially emerged canine, this specimen is like skulls of not fully matured individuals of *Smilodon californicus* (Nos. 2001–6, 8, 9 L. A. Mus. Coll.) from Rancho La Brea.

This type is the smallest representative of the *Hoplophoneus* group at present known from North America. It approaches in character of size the species *H. cerebralis* Cope, No. 6941 Amer. Mus. from the John Day deposits of Logan Butte, Oregon, but in several measurements is distinctly smaller (see table of measurements). The lack of full maturity may account for some of the difference between No. 463 and No. 6941. The Sespe specimen is likewise smaller than skull specimens, Nos. 5338 and 9764 Amer. Mus., referred to *H. oreodontis* and collected in the Oreodon beds of Colorado and South Dakota.

Fortunately the crushing of the skull has occurred in such a way as to permit recognition of the dorsal profile and of a number of characters normally seen in lateral aspect. When the skull is viewed with the alveolar border held horizontal, No. 463 exhibits the characteristic profile seen in sabretooth cat skulls. From the median point on the occipital crest, the major sweep of the dorsal outline is downward and forward. In the preparation of the specimen a small portion of the right postorbital process was broken away. This process appears to have been as well developed as in described species of *Hoplophoneus.* Unfortunately, the zygomatic arch is incompletely preserved, for a small ungulate phalanx is lodged against the skull behind and partly within the orbit. The occiput is narrow transversely with a small remnant of the sharp median crest still present on its upper portion. In size and shape of mastoid process No. 463 resembles *Hoplophoneus* with the process compressed in anteroexternal-posterointernal direction more so than in *H. cerebralis.* Insofar as the structures of the basicranial region can be discerned, these appear to resemble those of the Oligocene sabre-tooth.

The superior dentition includes the right canine, P$\underline{3}$ and P$\underline{4}$, and the left M$\underline{1}$. In the light of the series of *Smilodon* skulls from Rancho La Brea with permanent cheek-teeth present and in function in which the emergence of the permanent canine with replacement of the milk tooth is shown, the stage of development of the dentition in No. 463 clearly indicates that the canine in this specimen is a permanent and not a deciduous tooth. The right canine is slender and, in the light of the fragments of its fellow of the left side, never reached the size seen in described species of *Hoplophoneus*. In *H. cerebralis*, as Cope has noted, the canine is relatively large. The crown of the right canine projects 16 mm. below the alveolar border and at this margin has an anteroposterior diameter of 6.2 mm. As is shown by the space between the anterior border of the alveolus and the front edge of the tooth, the canine does not completely fill the socket. The posterior border of the exposed portion of the crown is minutely serrate.

Comparative measurements (in millimeters)

	Hoplophoneus belli, n.sp. Type No. 463 Sespe	*Hoplophoneus cerebralis* Cope No. 6941 Amer. Mus. John Day	*Hoplophoneus oreodontis* No. 9764 Amer. Mus. Oreodon Beds
Distance from posterior median point of occipital crest to anterior border of canine alveolus	101.3	112.6	131.7
Length from posterior end of mastoid process to anterior border of canine alveolus	84.8	102.5	*a*102.8
Length from anterior border of canine alveolus to posterior border of alveolus for M$\underline{1}$	44.6	*a*51.0	53.1
Length of diastema between canine and P$\underline{3}$	14.3	10.5	....
Greatest anteroposterior distance across glenoid fossa	10.4	12.4	12.5
$\underline{\text{C}}$, anteroposterior diameter at alveolar border	6.2	15.1	11.8
$\underline{\text{C}}$, transverse diameter at alveolar border	2.7	6.1	4.5
P$\underline{3}$, anteroposterior diameter	6.2	6.0	10.6
P$\underline{3}$, transverse diameter	3.0	2.8	5.1
P$\underline{4}$, anteroposterior diameter	14.7	*a*16.3	18.8
P$\underline{4}$, transverse diameter across protocone	5.5	6.4	10.0
M$\underline{1}$, anteroposterior diameter	3.6	....	4.5
M$\underline{1}$, transverse diameter	6.4	....	11.4
Length from anterior border of canine alveolus to posterior end of occipital condyle	100.7	....	*a*124.0

a, Approximate.

The diastema between the canine and P$\underline{3}$ is longer than in *H. cerebralis*, No. 6941 type. There is apparently no evidence, at least on the right side, of the presence of the second superior premolar. The alveolar border is not entirely preserved on the left side. This tooth may be present or absent in species of *Hoplophoneus*. P$\underline{3}$ and P$\underline{4}$ resemble in size the comparable teeth in Cope's species *H. cerebralis*. P$\underline{3}$ is not so well developed as in *Dinictis* and in side view is seen to differ from that in the latter genus and to resemble the third premolar of *Hoplophoneus* in the backward tilt of the crown. The crown is compressed laterally and possesses in addition to the principal cusp a very small anterior cuspule and a relatively large posterior cusp. The attitude of the crown in No. 463 brings the posterior portion of the tooth on the inner side of the parastyle of $P\underline{4}$ so that the posterior cusp is obscured from view in lateral aspect. The extent to which the tooth overlaps the inner wall of the carnassial is greater than that in *H. cerebralis.* It is less marked in the White River species *H. oreodontis* (No. 9764 Amer. Mus.).

$P\underline{4}$ is slightly smaller than the comparable tooth in the type specimen of *H. cerebralis,* and the parastyle is slightly smaller than in the latter species. The protocone may also be slightly less prominent in the Sespe type than in *H. cerebralis.* In *H. oreodontis* the latter cusp is more prominently developed, but in No. 9764 referred to this species the parastyle is less evident than in No. 463. With lack of prominence of protocone, the inner wall is flattened in the Sespe specimen. The outer surface of the crown is noticeably concave in fore and aft direction between the midline of the paracone and the end of the posterior shearing blade. $M\underline{1}$ is apparently no more reduced than in typical species of the genus.

In absence of $P\underline{2}$, presence of a distinct parastyle on $P\underline{4}$, and possibly in the overlapping of the crowns of $P\underline{3}$ and $P\underline{4}$, *Hoplophoneus belli* appears to be more advanced than species known from the White River Oligocene. In the reduction of the anterior premolars and in the characters of the upper carnassial *H. belli* has acquired evidently considerable specialization. *H. belli* is smaller than *H. oreodontis* and approaches in size *H. cerebralis* from the John Day. The Sespe species also resembles the latter in absence of $P\underline{2}$ and size of $P\underline{3}$, but differs in the presence of a more slender canine and probably in the smaller size and less-developed parastyle of $P\underline{4}$ and greater overlapping of $P\underline{3}$ and $P\underline{4}$.

Nimravus meridianus n. sp.

Type specimen—Fragmentary right ramus of mandible with canine, $P\overline{3}$, $P\overline{4}$ and $M\overline{1}$, No. 462 Calif. Inst. Tech. Coll. Vert. Pale., Plate III, fig. 1. Collected at Kew Quarry, Locality 126.

Specific characters—Slightly smaller than *Nimravus confertus* and with anterior end of ramus slender. Diastema longer than in the John Day type. No marked angulation of antero-inferior border. Symphysis extends farther posteriorly than in *N. confertus.*

Description—No. 462 resembles most closely in size *N. confertus* of the several species of *Nimravus* known from the John Day. The body of the jaw beneath the cheek-teeth is crushed laterally and this has probably increased, at least slightly, the depth of the ramus. Nevertheless, that portion of the jaw lying in front of $P\overline{3}$ appears slender, relatively more so than in described species of *Nimravus.* An anterior mental foramen is situated below the diastema between canine and $P\overline{3}$ and midway between the superior and inferior borders, while a posterior foramen is present below the posterior end of the third premolar. No sharp angle is defined at the antero-inferior corner of the ramus. The border outlining the anterior end of the lateral surface of the ramus extends downward and backward, swinging around the antero-inferior angle to form a crest on the inferior surface. This extends backward to a point below the posterior end of $P\overline{3}$.

The symphysis extends farther posteriorly in the Sespe specimen than in the type of *N. confertus.* Cope has commented on the reduced size of the symphyseal region in the latter species and Eaton has also noted this character in a specimen, No. 10046 Yale Univ. Coll., from the John Day.

In No. 462 the canine is slender, but little of the crown remains. The tooth-row, $P\overline{3}$–$M\overline{1}$, is actually shorter than in *N. confertus.* An alveolus indicates the presence of a second molar. The cheek-teeth have positions

Comparative measurements (in millimeters)

	N. meridianus Type No. 462 C.I.T. Sespe	*N. confertus* Type No. 6936* Amer.Mus. John Day	*N. debilis* Type No. 6930* Amer.Mus. John Day	*N. debilis major* Type No. 1679* U.C.C. John Day	*N. gomphodus* Type No. 6933 Amer.Mus. John Day	*N. sectator* Type No. 12882 Amer.Mus. Lower Rosebud
Depth of mandible below middle of diastema, normal to inferior border....	19.3	20.0	20.0	31.0	27.0	29.3
Depth of mandible at posterior end of $P\bar{4}$, normal to inferior border.......	23.3	....	24.0	37.0	31.5	31.7
Length of diastema between C and $P\bar{3}$..................................	15.2	12.9	21.0	25.0	23.0	17.6
Length from anterior end of $P\bar{3}$ to posterior end of $M\bar{1}$..................	46.2	48.6	53.2	....	57.5	63.1†
$P\bar{3}$, anteroposterior diameter..	12.6	13.3	14.6	17.0	17.0	....
$P\bar{4}$, anteroposterior diameter..	15.2	16.0	17.8	19.5	20.0	20.3
$M\bar{1}$, anteroposterior diameter..	21.8	22.5	24.4	27.0	25.0	28.4

*Measurements in part after J. C. Merriam.

†Alveolar measurement.

oblique to the antero-posterior axis of the jaw, in which respect the Sespe specimen differs from the type of *N. confertus.* Lateral crushing of the jaw may have accentuated somewhat the obliquity of the teeth, but does not seem to account entirely for this position.

In $P\bar{3}$ the principal cusp is prominent, slightly more so than in the type of *N. confertus* from the John Day, No. 6936 Amer. Mus. A rudimentary basal cuspule is situated at the anterior end of the principal cusp. In $M\bar{1}$ the notch between the two shearing blades is deep and open, although not so widely open as in the type of *N. debilis,* No. 6930 Amer. Mus. The heel in this tooth is relatively small.

No extensive exostosis is evident along the alveolar border of $M\bar{1}$ in the Sespe specimen. A prominent lateral border below and in front of the alveolus for the second molar may represent the beginning of an exostosis. In view of the frequent development of a swelling along the lateral alveolar border of $M\bar{1}$ and $M\bar{2}$ in the John Day representatives of the *Nimravus* group, the absence of a clear example of exostosis in the Sespe specimen appears rather unique. As indicated, there is a suggestion of an increase in size of surface in the enlarged ridge, but the latter is of short extent and in front of this the lateral wall is flattened. Merriam has shown that the exostosis is of variable size in specimens from the John Day beds. Although moderately developed in *N. confertus,* the exostosis is much better defined in this form than in *N. meridianus.*

Nimravus meridianus differs noticeably in size from the John Day species *N. debilis* and *N. gomphodus,* approaching the species *N. confertus* more nearly in this character. *N. sectator,* No. 12882 Amer. Mus., from the lower Rosebud, is a distinctly larger form than No. 462 from the Sespe. No. 12882 differs also in the presence of a shorter diastema between canine and $P\bar{3}$, less tendency toward oblique position of lower premolars, and absence of $M\bar{2}$.

SUMMARY AND CONCLUSIONS

The Carnivora from the Sespe deposits (Kew Quarry) in the Las Posas Hills, Ventura County, California, are represented by five specific types. While this number is distinctly less than that recorded from the John Day beds, the presence of five comparable forms in the Sespe of the Las Posas Hills and in the John Day suggests a close faunal relationship between the two horizons. The striking resemblance between the two stages is expressed by the following comparative lists:

SESPE, LAS POSAS HILLS	JOHN DAY
Pseudocynodictis(?) pavidus	*Cynodictis(?) oregonensis*
Mesocyon baileyi	*Mesocyon brachyops*
Temnocyon cf. altigenis	*Temnocyon altigenis*
Hoplophoneus belli	*Hoplophoneus cerebralis*
Nimravus meridianus	*Nimravus confertus*

Two of the five genera and species, namely *Pseudocynodictis(?) pavidus* and *Hoplophoneus belli,* have related forms in the White River. *H. belli,* however, is more advanced than typical representatives of the *Hoplophoneus* group in the White River.

PLATE 1

Pseudocynodictis(?) pavidus n. sp.

FIGS. 1-5. Crushed skull and mandible, type specimen, No. 466 Calif. Inst. Tech. Coll. Vert. Pale. Figs. 1 and 2, x 1; figs. 3 and 4, right ramus of No. 466, x 1½; fig. 5, right lower canine of No. 466, x 1½.

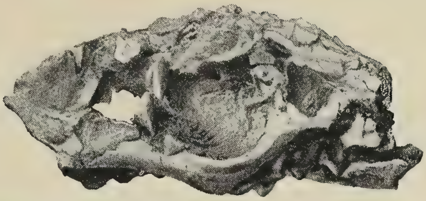
Temnocyon cf. altigenis Cope

FIG. 6. Right ramus, No. 470 Calif. Inst. Tech. Coll. Vert. Pale.; x ½.

Mesocyon baileyi n. sp.

FIGS. 7 and 8. Skull fragment with right C—$\underline{M2}$, No. 1242 Calif. Inst. Tech. Coll. Vert. Pale., lateral and inferior views; x 1.

Sespe Oligocene, Las Posas Hills, California.



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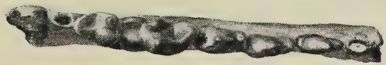

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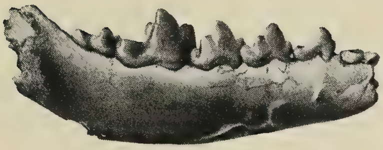

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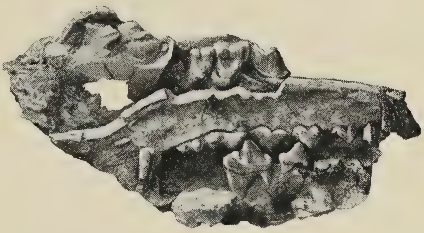

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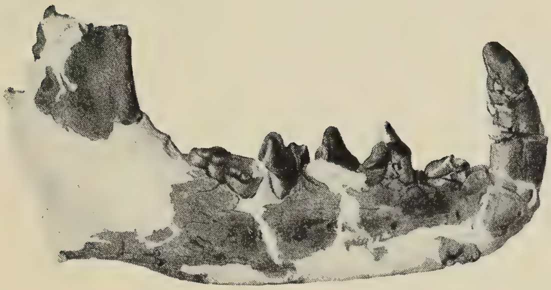

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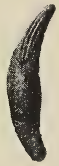

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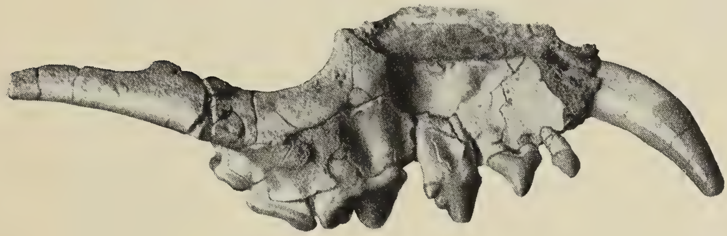

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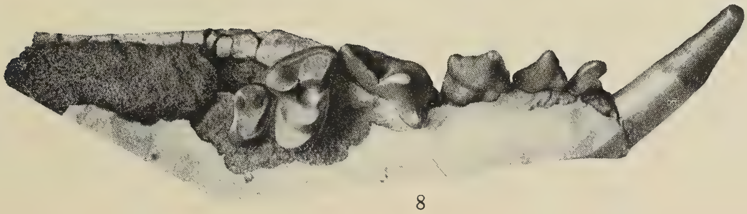

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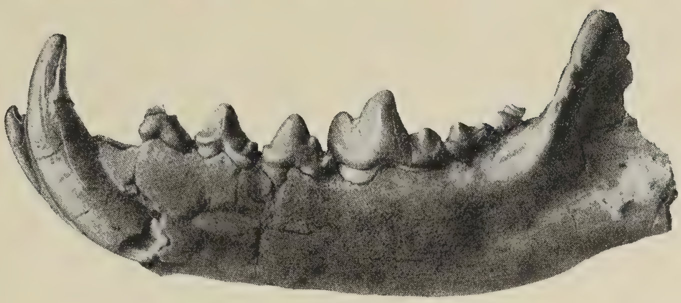
PLATE 2.

Mesocyon baileyi n. sp.

FIGS. 1-3. Crushed skull and mandible, type specimen, No. 471 Calif. Inst. Tech. Coll. Vert. Pale.; x 1. Fig. 1, left ramus; figs. 2 and 3, skull, lateral and inferior views. Sespe Oligocene, Las Posas Hills, California.



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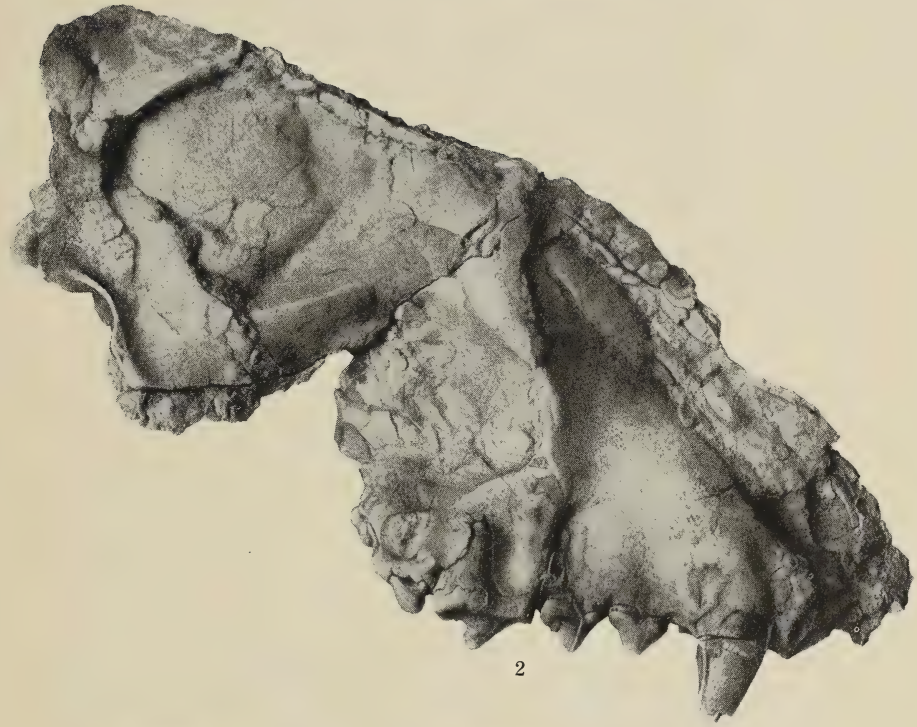

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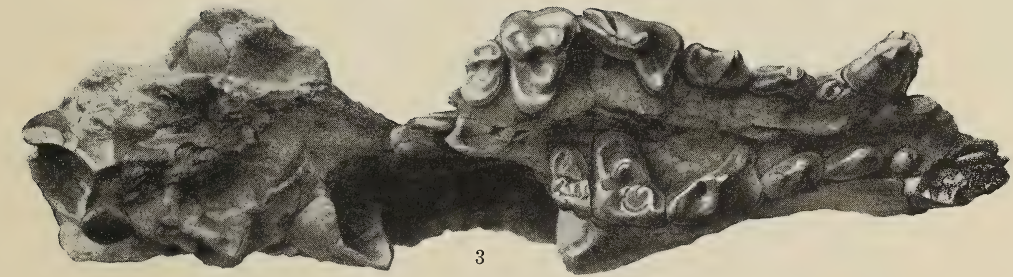

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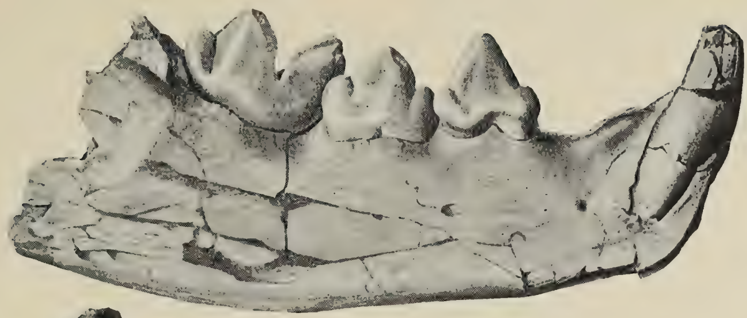
PLATE 3.

Nimravus meridianus n. sp.

FIG. 1. Right ramus, type specimen, No. 462 Calif. Inst. Tech. Coll. Vert. Pale.; x 1.

Hoplophoneus belli n. sp.

FIGS. 2 and 3. Crushed skull, type specimen, No. 463 Calif. Inst. Tech. Coll. Vert. Pale.; x 1. Sespe Oligocene, Las Posas Hills, California.



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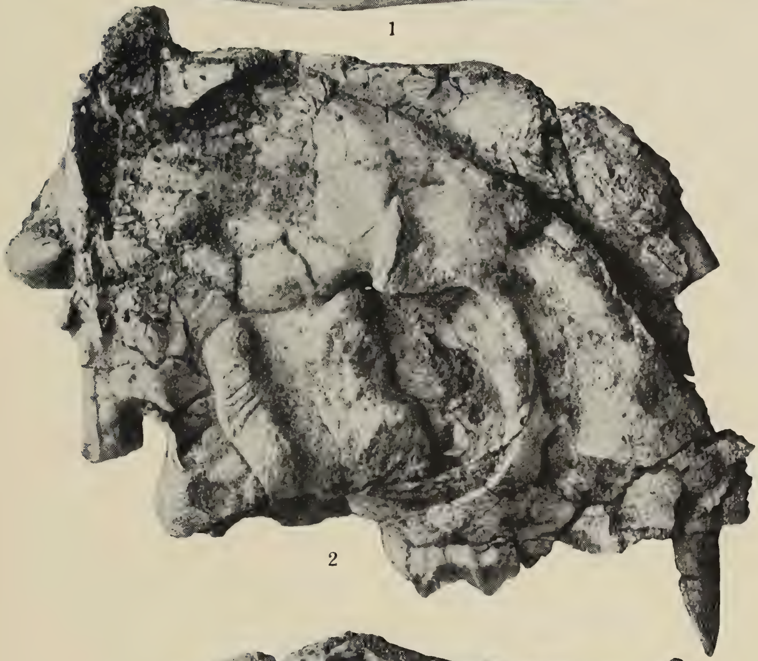

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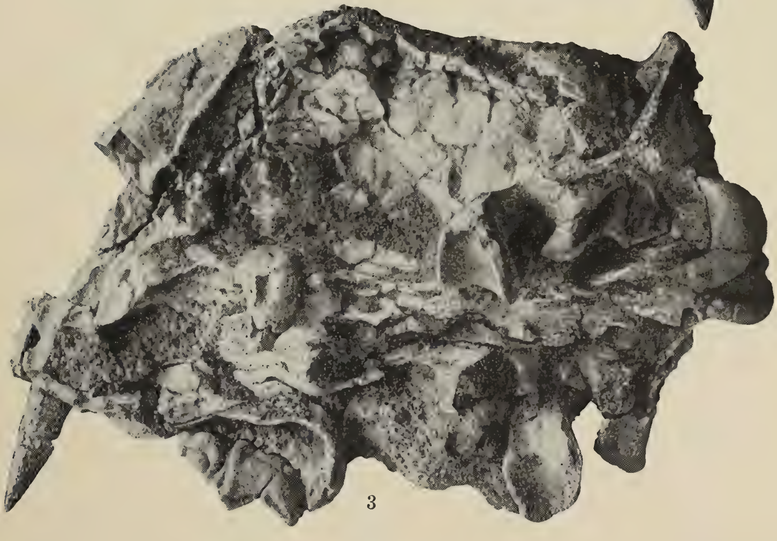

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ANCHITHERIINE HORSES FROM THE MERYCHIPPUS ZONE OF THE NORTH COALINGA DISTRICT, CALIFORNIA

By Francis D. Bode

With five plates

[Issued November 1933]

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ANCHITHERIINE HORSES FROM THE MERYCHIPPUS ZONE OF THE NORTH COALINGA DISTRICT, CALIFORNIA

INTRODUCTION

Excavations by the California Institute of Technology in the Merychippus zone of the North Coalinga district, California, have added considerably to our knowledge of the Equidæ from this horizon. In addition to a large amount of material representing the genus *Merychippus,* the teeth of three genera of anchitheriine horses have been found. These teeth are of value in that they furnish additional information regarding the taxonomic position and geographic distribution of several of the middle Tertiary genera known from the Pacific Coast and Great Basin provinces.

The writer is indebted to the Department of Paleontology, University of California, for loan of comparative material, including type specimens, from the Barstow and Mascall formations. Dr. Walter Granger of the American Museum of Natural History has kindly permitted the writer to study and figure a specimen of *Archæohippus penultimus* Matthew from the Sheep Creek beds of western Nebraska. Dr. C. L. Gazin of the United States National Museum likewise has kindly permitted the description of a mandible found by him in Cajon Pass, California. The writer is indebted also to Dr. Chester Stock for his criticism given during the course of this study and for his aid in making comparisons of the described material from the Merychippus zone with types in the American Museum and elsewhere in the east. The illustrations reproduced in the plates are from photographs that have been accurately and carefully retouched by Mr. John L. Ridgway.

The material from the Merychippus zone was obtained in part from the type locality on Domengine Creek, north of Coalinga, where the original collections were made by the University of California which formed the basis of the important contribution published by J. C. Merriam[1] in 1915. The specimens were collected in the course of rather extensive excavations in a zone of sandstones and conglomerates 2 or 3 feet thick lying at the top of the middle Miocene "Temblor" section on Domengine Creek and immediately below the Miocene beds known as the "Big Blue." In addition, large collections of fossil remains were obtained at a new quarry-site along the strike of the beds one-fourth mile south of the type locality and at a position approximately 20 feet stratigraphically below the Temblor-Big Blue contact.

The material found at both localities consists for the most part of scattered teeth and limb elements. Some of the specimens have suffered considerably from abrasion, probably due to transportation by or movement in water.

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[1] J. C. Merriam, Trans. Amer. Philos. Soc., n.s., vol. 22, pt. 3, 44 pp., 1915.

SYSTEM OF MEASUREMENTS

On superior cheek-teeth the anteroposterior diameter is the distance measured across the base of the crown from the middle of the faces of contact with the adjoining anterior and posterior teeth. The height of the crown is measured only on unworn specimens. It is the maximum distance from the base of the crown to the top of the paracone. The transverse diameter is measured across the base of the crown from the point of deepest indentation of the paracone wall to the farthest lingual projection of the protocone. In second premolars the transverse diameter is measured at the base of the crown from the point of deepest indentation of the metacone wall to the farthest lingual projection of the hypocone.

On inferior cheek-teeth the height of the crown, measured only on unworn teeth, is the maximum distance from the base of the crown to the top of the protoconid. The anteroposterior diameter is the greatest distance taken across the tooth from the anterior to the posterior side, including the entostylid. The transverse diameter is the minimum distance at the base of the crown from the farthest external projection of the protoconid to the lingual side of the tooth. On second premolars this diameter is taken in a similar manner across the tooth from the hypoconid.

DESCRIPTION OF SPECIES

Hypohippus sp.

This genus is represented in the collections from the Merychippus zone by an upper molar, No. 885, and three lower premolars, Nos. 886, 887 and 888, Calif. Inst. Tech. Coll. Vert. Pale., Plate 1, figures 6 to 9.

Measurements (in millimeters)

	No. 885 $M\underline{1}$	No. 886 $P\overline{2}$	No. 887 $P\overline{4}$?	No. 888 $P\overline{3}$?
Anteroposterior diameter..........	18.7	19.8	19.5	19.0
Transverse diameter..............	25.3	13.5	16.3	16.0

The superior molar is well worn. The anteroposterior diameter is less than that of any described species of *Hypohippus*. The transverse diameter is comparable to that found in *H. osborni*. The walls of the metaloph are simple with no indication of a crochet. The protoconule is smaller than the protocone. An internal cingulum is absent. The hypostyle is relatively weak.

The lower premolars are slightly smaller than those for any described species of *Hypohippus*. These teeth are distinguished from *Parahippus* by the absence of an entostylid and of the groove on the inner wall of the metaconid-metastylid column. In Nos. 886 and 888 the anterior end of the posterior loph does not connect with the metaconid. A heavy external cingulum is present on two of the teeth but is absent on the third, No. 886.

The material is inadequate for more than a generic determination.

Parahippus brevidens Marsh

The genus *Parahippus* is represented in the collections of the California Institute from the Merychippus zone by approximately 20 well-preserved upper and lower cheek-teeth, Plate 1, figures 1 to 5 and 10 to 18.

The upper cheek-teeth are relatively high crowned and generally well cemented. An internal cingulum is absent. The external walls of the paracone and metacone are smooth with practically no indication of a median ridge. The protoloph is usually continuous and is bent almost at right angles between the protocone and protoconule. The protocone is conical in shape. The metaloph is attached to the ectoloph. One or more crochets are always present on the anterior side of the metaloph. The middle portion of this loph usually exhibits a number of ptychoid crenulations of the enamel on both anterior and posterior walls. The hypocone is ridge-shaped and essentially a continuation of the metaloph. The hypostyle is a strong cusp, triangular in cross-section, which encloses a small fossette. The third upper molar is considerably reduced in size and possesses a heavy coating of cement. The greatest transverse diameter in the superior cheek-tooth series probably occurs in $P\underline{4}$, since teeth referable to the two posterior premolar positions are larger than any of the teeth identified as molars.

The lower cheek-teeth are small and relatively light. A faint external cingulum is present. In unworn teeth the metaconid-metastylid column is defined by the internal groove in the upper half of the crown. An entostylid is but weakly developed. The amount of cement present is variable but is usually heavy in the protoconid-hypoconid valley. Cement is also present as a rule in the valleys on the lingual side of the tooth. The inner cusps are expanded at the base so that the entrance to the lingual valleys is narrowed. The enamel walls are smooth with no indication of striæ.

The ptychoid crenulations noted on the walls of the metaloph and the heavy coating of cement on most of the teeth serve to distinguish immediately the material referred to *Parahippus* from the Merychippus zone, from most of the recorded species of *Parahippus*.

The Coalinga specimens agree closely with teeth of *Parahippus crenidens* Scott in the development of the crochets and in the crenulations of the walls of the metaloph. They differ from those of *P. crenidens*, however, in their heavy coating of cement, less strongly developed ectoloph, shape of the protoloph, and in the presence of only a faint external cingulum on the lower teeth.

The deciduous teeth of *Parahippus cognatus* show progressive characters similar to those found in the permanent teeth from the Merychippus zone. This species can not be compared satisfactorily, however, since no deciduous teeth of *Parahippus* are available from the Temblor beds, north of Coalinga. Judging from the size of the milk-teeth in *P. cognatus* it seems probable that this species represents a much larger horse than that from the north

Coalinga horizon. Moreover, it appears to be safe to assume that the two forms are not conspecific.

A comparison with *Parahippus brevidens* Marsh from the Mascall beds in eastern Oregon fails to reveal any characters whereby the Coalinga specimens can be separated from this species. Two teeth referred to *P. brevidens* collected from the Mascall (Calif. Inst. Coll. Vert. Pale. Nos. 406 and 407) are almost identical with teeth from the Merychippus zone. As far as the writer is aware no lower cheek-teeth referable to *P. brevidens* have been described from the Mascall. It is interesting to note that the lower teeth of *Parahippus* from the Merychippus zone are quite distinct from those of *P. avus*, a second species recorded in the Mascall fauna. The lower cheek-teeth of *P. avus* are large and heavy with a strong external cingulum. The metaconid and metastylid are widely separated, the entostylid is a strong cusp, and the external walls of the inferior teeth are noticeably rugose. Thus additional evidence would seem to indicate that the two species from the Mascall are distinctly separable.

Measurements (*in millimeters*)

Calif. Inst. Tech. Coll.	Height of crown	Anteroposterior diameter	Transverse diameter
P$\underline{2}$, No. 1148	....	a23.8	20.5
P$\underline{4}$?, No. 1147	15.6	19.8	22.1
M$\underline{1}$?, No. 1145	15.0	18.5	21.9
M$\underline{1}$?, No. 1144	14.8	16.8	21.7
M$\underline{2}$?, No. 1146	15.4	17.5	22.3
M$\underline{3}$, No. 1150	12.0	14.4	a17.0
M$\underline{3}$, No. 1151	....	13.3	....
P$\overline{4}$, No. 1142	....	18.8	11.8
M$\overline{1}$, No. 1143	....	17.7	11.7
M$\overline{1}$?, No. 1141	17.6	17.2	11.5
M$\overline{3}$?, No. 1152	....	20.3	11.1
P$\underline{4}$, No. 406	....	18.7	22.9
M$\underline{3}$, No. 407	15.0	17.6	20.5

a, Approximate. Nos. 406 and 407 from Mascall middle Miocene, Oregon.

Archæohippus mourningi (Merriam)

Archæohippus is more abundantly represented by material in the collection from the Merychippus zone than either *Hypohippus* or *Parahippus*. The specimens comprise a lower jaw, No. 484, with P$\overline{3}$–M$\overline{3}$; a composite series of unassociated superior cheek-teeth, No. 881, with P$\underline{4}$–M$\underline{3}$; an unworn Dp$\underline{3}$, No. 883; and in addition 20 superior and 15 inferior isolated molars and premolars; Plate 2, figures 1 to 5.

The superior cheek-teeth are brachydont though relatively high-crowned. The enamel is sometimes slightly rugose. An external cingulum is present on the paracone and metacone walls but does not connect across the mesostyle. A lingual cingulum is absent on most of the teeth but is faintly present on two specimens and distinct on a third. P$\underline{1}$ is not represented in the collection. The premolars are larger than the molars. The greatest transverse diameter probably occurs in P$\underline{4}$. M$\underline{3}$ is reduced in size, the posterior wall of the tooth showing a marked transverse compression. All of the teeth are devoid of cement. A faint but distinct median ridge is present on the external wall of the paracone but is usually absent on the metacone. The protoloph is rectilinear in outline. The protoconule is elongate and flattened with a straight, sharp, ridge-like appearance in unworn teeth. The protocone is distinctly conical in shape and is firmly attached to the protoloph. The anterior wall of the protoloph is deeply notched between protoconule and protocone and a prominent anterior cingulum extends across the notch, forming almost a small cusp in the center. The metaloph is always united with the ectoloph. The walls of the metaloph are smooth with no indication of a crochet, although in several teeth there are a few small plate-like projections which arise from the extreme antero-external end of the metaloph. The metaconule is a thin compressed ridge that curves slightly as the metaloph turns to join the ectoloph. The anterior wall of the metaloph is notched, giving the hypocone a conical appearance. The posterior wall of the metaloph is straight and unbroken. The hypostyle is large and triangular in shape. It is formed by an L-shaped crescent which is connected at its posterior end with a strongly developed portion of the postcingulum, inclosing a small triangular area.

The superior deciduous dentition is represented by Dp$\underline{3}$, No. 883. The parastyle is small and relatively feebly developed. The median ridge on the external wall of the paracone is strongly developed, giving this cusp a conical appearance. A distinct cingulum is present across the entire lingual side of the tooth. The height of the crown in this tooth is comparable to that found in teeth of the permanent dentition.

The inferior cheek-teeth are uncemented. The crowns of the molars and premolars are usually smooth, although the external walls are sometimes marked by a series of thin horizontal lines. In the lower jaw (No. 484) P$\overline{4}$ and P$\overline{3}$ are larger than the molars, with the greatest transverse diameter of the series occurring on the posterior portion of P$\overline{4}$. An external cingulum is present on the teeth of No. 484. An internal cingulum is only faintly defined on a few of the teeth. With the exception of the posterior side of M$\overline{3}$, an anterior and a posterior cingulum is present on all of the inferior teeth. The metaconid and metastylid are separated at the summit of the crown but become connected at an early stage of wear. The entostylid is well developed but does not stand so high as the entoconid in unworn teeth. There is usually a distinct median ridge on the inner walls of the protoconid and hypoconid. A single P$\overline{1}$, C.I.T. No. 1223, shows that this tooth was two-rooted with a simple, thin, almost trenchant crown. In M$\overline{3}$ the entostylid is a distinct conical cusp smaller than the hypoconid and connected with the entoconid-hypoconid wall by a thin plate-like projection. A small additional cusp is present near the base on the lingual side between the entoconid and entostylid.

The *Archæohippus* material from the Merychippus zone represents a more advanced type than *A. ultimus* (Cope) from the Mascall. In *A. ultimus* the hypostyle is a single cusp formed only by a strengthening of the postcingulum. In the Coalinga form this cusp is triangular in shape and incloses a small fossette. The type of *A. ultimus* shows that in this species M$\underline{3}$ is unreduced. Several third upper molars collected from the Merychippus zone show that in the Coalinga form M$\underline{3}$ is noticeably reduced. The protocone and hypocone are smaller in the Mascall form. Unlike the cusps in the Coalinga species they do not widen sufficiently at the base to obstruct the entrance to the valley between protoloph and metaloph. The median external rib on the paracone wall is much more distinct in *A. ultimus*. None of the teeth from the Merychippus zone exhibits an internal cingulum comparable to the heavy cingulum present on the paratype from the Mascall. The height of the crown of the cheek-teeth in *A. ultimus* is comparable to that found in advanced forms of *Miohippus*. In extreme height of crown the Coalinga specimens appear precocious for an anchitheriine horse with such small teeth.

With the exception of the height of crown the lower cheek-teeth of *A. mourningi* and *A. ultimus* are quite similar.

The teeth of *Archæohippus penultimus* Matthew compare closely in structure with those belonging to the species from the Merychippus zone. In the Coalinga specimens the parastyle and mesostyle are more strongly developed. The median external rib on the paracone wall is more noticeable in *A. penultimus*. The valley between the protoloph and metaloph is slightly wider than in specimens from the Merychippus zone. The enamel pattern of the upper cheek-teeth is essentially similar in these two species. In the lower cheek-teeth the separation of the metaconid-metastylid column is slightly more in evidence in the Coalinga specimens.

The structural characters seen in the cheek-teeth suggest that the two forms are very closely related. In view of present uncertainty as to their geologic time relations and their wide geographical separation it seems advisable to recognize *A. mourningi* and *A. penultimus* as specifically distinct on the basis of the characters outlined above.

The teeth from the Merychippus zone agree with the type and paratype of *Archæohippus mourningi* (Merriam) from the Barstow in almost every particular. In the type, M$\underline{1}$ is practically inseparable from molars assigned to the same position from the Merychippus zone. The principal difference is presented by the absence of an external cingulum on the premolars of the paratype. However, the presence or absence of an external cingulum appears to be a variable character and thus of slight diagnostic value. In the collection of 21 isolated lower cheek-teeth of *Archæohippus* from the Merychippus zone the external cingulum is absent in 8 teeth, faint to indistinct in 7, and distinct in only 6. The lower jaw from the Barstow is slightly larger than No. 484 from the Coalinga locality. The difference in size may well be within the limits of individual variation as several teeth from the north Coalinga district exceed the Barstow paratype in size.

Measurements (*in millimeters*)

Calif. Inst. Tech. Coll.	Height of crown	Anteroposterior diameter	Transverse diameter
No. 881:[1]			
P$\underline{4}$	12.1	13.1	15.3
M$\underline{1}$	....	12.3	15.6
M$\underline{2}$	10.2	11.2	14.6
M$\underline{3}$	9.7	10.2	13.0
M$\overline{3}$, No. 884	9.5	14.0	8.2
Dp$\underline{3}$, No. 883	8.6	11.0	10.6
M$\underline{3}$, No. 882	....	12.7	10.3
Ramus, No. 484:[2]			
P$\overline{3}$	9.2	13.0	9.0
P$\overline{4}$	10.2	12.5	9.7
M$\overline{1}$	....	11.8	9.2
M$\overline{2}$	....	12.0	8.9
M$\overline{3}$	10.0	13.9	8.3

[1] Teeth listed under this number are not all of one individual.

[2] Length from anterior end of P$\overline{3}$ to posterior end of M$\overline{3}$, 65.9.
Depth of ramus below middle of M$\overline{1}$ normal to inferior border, 21.9.
Width of ramus below middle of M$\overline{1}$ (thickness), 8.0.

PREVIOUSLY DESCRIBED OR NEW MATERIAL REFERRED OR RELATED TO ARCHÆOHIPPUS

Most of the material referred to *Archæohippus* from Miocene horizons in North America has been described but not figured. Since the original descriptions of the three species of *Archæohippus*, new material has come to light which better illustrates the characters of the genus.

Opportunity is taken, therefore, to review particularly the dental characters of previously described specimens and to consider also the new material on which to base a more complete definition of the genus than has been attempted heretofore.

Archæohippus ultimus (Cope)

Genotype—The anterior portion of a skull with a nearly complete dentition, No. 8174 Amer. Mus. Coll., described by Gidley[1] from Mascall beds on Cottonwood Creek, Oregon.

Paratype—Several isolated teeth; one an upper molar, No. 1689 Univ. Calif. Coll., described by Gidley[2] from Mascall beds, and figured by Merriam[3] and by Osborn.[4]

Referred specimens—An unworn lower molar, No. 3059 Univ. Calif. Coll.; an unworn lower premolar, Calif. Inst. Coll. No. 424, and a much worn inferior molar, No. 31987 Univ. Calif. Coll.; Plate 3, figures 1-4. All specimens from the Mascall deposits.

Measurements (in millimeters)

	Height of crown	Anteroposterior diameter	Transverse diameter
Type No. 8174 Amer. Mus. Coll.:*			
P$\underline{2}$		14.5	14.1
P$\underline{3}$		12.4	15.7
P$\underline{4}$		13.1	15.8
M$\underline{1}$		*a*10.8	*a*14.6
M$\underline{2}$		*a*11.0	*a*14.9
M$\underline{3}$		*a*11.0	*a*14.1
Paratype:			
M$\underline{3}$?, No. 1689 U. C. Coll	8.8	11.1†	14.2†
Molar:			
No. 3059 U. C. Coll	9.0	12.6	7.8
Premolar:			
No. 424, C.I.T. Coll	10.3	13.5	9.5
Molar:			
No. 31987, U. C. Coll		11.5	8.3

* Length from anterior end of P$\underline{1}$ to posterior end of M$\underline{3}$, 78.2.

Length from anterior end of P$\underline{1}$ to posterior end of P$\underline{4}$, 45.5.

† These measurements differ from those given by Merriam, due to the use of a slightly different system of measurements.

a, Approximate.

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[1] J. W. Gidley, Bull. Amer. Mus. Nat. Hist., vol. 22, 385–388, 1906.

[2] J. W. Gidley, *ibid.*

[3] J. C. Merriam, Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, 428, fig. 4, 1913, and vol. 11, 476, fig. 35, 1919.

[4] H. F. Osborn, Mem. Amer. Mus. Nat. Hist., vol. 2, pt. 1, 213, fig. 173 (4), 1918.

In the type skull the enamel pattern of the teeth is in large measure obliterated by wear. The development of an internal cingulum is variable. The basal ledge is well defined on the entire lingual side of P$\underline{2}$. It is absent on the lingual side in P$\underline{3}$ to M$\underline{1}$. A cingulum is present at the base of the protocone only in M$\underline{2}$ and M$\underline{3}$. A well-developed cingulum is present on the walls of the paracone and metacone but does not extend across the base of the mesostyle. The valley opening between the protoloph and metaloph is not constricted at the lingual entrance as in *Archæohippus mourningi.*

The lower teeth are slightly smaller than those of *A. mourningi* and of *A. penultimus.* The worn tooth, No. 31987, from the Mascall has a strong internal cingulum as well as external cingulum. An external cingulum is present around the protoconid but is absent on the hypoconid in No. 424. The protoconid and hypoconid of No. 3059 U. C. Coll. have no cingula. No trace of a separation of the metaconid-metastylid exists in the tooth, No. 31987, because of the extreme wear of the crown. The separation is but faintly defined in No. 3059, but it occupies the upper one-third of the crown in No. 424. The walls of the crowns are slightly rugose. All of the teeth are devoid of cement.

Archæohippus penultimus Matthew

Type—Fragment of a lower jaw with P$\overline{3}$–M$\overline{1}$, No. 18950 Amer. Mus. Coll.

Paratype—An isolated lower molar No. 18951 Amer. Mus. Coll. Both the type and paratype were described by Matthew[1] from the Sheep Creek beds in Stonehouse Quarry Draw, Sioux County, Nebraska.

In the type jaw fragment, the three teeth have been considerably worn. This wear has obliterated all trace of the original separation of the metaconid-metastylid column. The paratype is more moderately worn and retains a slight indication of the gutter separating the metaconid from the metastylid. In both the type and paratype an external cingulum is absent.

Since the above material was collected, the American Museum has obtained additional material from the lower Sheep Creek beds in Aphelops Draw at the Snake Creek quarries. The specimens include a rather complete palate with Dp$\underline{1}$–Dp$\underline{4}$ and M$\underline{1}$, No. 21534 Amer. Mus. Coll. and a well-preserved mandible, probably of the same individual, with Dp$\overline{2}$–Dp$\overline{4}$ and M$\overline{1}$, No. 21532 Amer. Mus. Coll., Plate 4, figures 1-2. This material has been referred by Matthew to *Archæohippus penultimus.*

In the palate a deep restricted preorbital fossa is very well shown. The enamel on the walls of the teeth is smooth. A faint external cingulum is present at the base of the paracone and metacone, but is interrupted by the mesostyle. An internal cingulum is present on Dp$\underline{2}$ only. In Dp$\underline{2}$ the parastyle is large and well developed and slightly larger than the paracone, which is conical in shape. P$\underline{1}$? is a large tooth and appears to have roots which are fused. A median ridge is present on the wall of the paracone in all of the teeth, but it is sometimes faint or indistinct. The parastyle and mesostyle are weakly developed when compared with the comparable styles in *A. ultimus* and in *A. mourningi.* The protoloph is unbroken and rectilinear in outline. It is sharply constricted between the protocone and protoconule. The metaloph is a thin ridge which flares posteriorly to produce the hypocone. There is no indication of a crochet on any of the teeth. The metaconule can not be distinguished from the metaloph. In the milk teeth the protoconule is approximately as large as the protocone. The protocone and hypocone are conical in shape and are set far apart so that the valley opening between them is not constricted. The hypostyle is a well-developed cusp, triangular in shape and inclosing a small fossette. All of the teeth are uncemented.

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[1] W. D. Matthew, Bull. Amer. Mus. Nat. Hist., vol. 50, 158, 1924.

In common with other members of the Anchitheriinæ, the inferior deciduous teeth of No. 21532 exhibit a greater degree of separation of the metaconid-metastylid than do the permanent teeth. In the milk teeth of this specimen a groove occupies the upper half of the height of the crown, while the separation exists only in the upper fourth of the permanent molar. A cingulum is present on all of the inferior teeth on the anterior and external sides of the protoconid. In the milk teeth a well-developed ledge is present between the protoconid and hypoconid. An external cingulum is present only on the hypoconid of Dp$\overline{2}$. In Dp$\overline{2}$ the paraconid and protoconid are of equal size. The paraconid is situated in front of and only slightly interior to the antero-external cusp. The metaconid is placed almost directly inside of the protoconid, so that the anterior loph in this tooth forms almost a right angle. The valley between the protoconid and hypoconid slopes downward and to the rear, while its position is almost vertical in the deciduous teeth posterior to the second. The alveolus for Dp$\overline{1}$ indicates that this tooth was single-rooted. All of the teeth are uncemented. The walls of the deciduous teeth are slightly rugose, while the walls of M$\overline{1}$ are smooth. The symphyseal region of the jaw is thin and delicate and flattened horizontally.

Measurements (in millimeters)

Amer. Mus. Coll.	Height of crown	Anteroposterior diameter	Transverse diameter
Paratype:			
Inferior molar			
No. 18951	....	12.8	8.5
Palate*			
No. 21534			
P$\underline{1}$	....	10.5	6.5
Dp$\underline{2}$	....	15.9	12.5
Dp$\underline{3}$	....	13.5	12.8
Dp$\underline{4}$	....	13.9	13.2
M$\underline{1}$	11.7	13.1	14.8
Mandible*			
No. 21532			
Dp$\overline{2}$	....	16.4	8.3
Dp$\overline{3}$	....	13.7	9.3
Dp$\overline{4}$	....	14.1	9.5
M$\overline{1}$	10.5	14.4	9.3

Length from anterior end of P$\underline{1}$ to posterior end of M$\underline{1}$, 60.2.
Length from incisor alveolar border to posterior border of vertical ramus, 166.8.
Length of tooth row Dp$\overline{2}$–M$\overline{1}$ inclusive, 58.3.
Depth below middle of M$\overline{1}$, normal to inferior border, 23.3.
Width below middle of M$\overline{1}$ (thickness), 13.2.
Height from inferior border to tip of coronoid process, 85.2.
* Measurements taken on right side of mandible and palate.

Archæohippus mourningi (Merriam)

Type—Portion of a maxillary with Dp$\underline{3}$–Dp$\underline{4}$ and M$\underline{1}$, No. 19840 Univ. Calif. Coll., Plate 3, figure 5.

Paratype—Portion of a ramus with dentition representing P$\overline{2}$–M$\overline{2}$, No. 19764 Univ. Calif. Coll., plate 3, figure 6. Both the type and paratype were described by Merriam[1] from the Barstow upper Miocene, Mohave Desert, California.

The full description of these specimens by Merriam requires little addition, except that the alveolus for P$\underline{1}$ shows that this tooth was two-rooted. The species was referred provisionally to the genus *Parahippus* and was assigned later to the genus *Archæohippus* by Osborn.[2] The material discovered in the quarries of the Merychippus zone substantiates Osborn's determination.

*Measurements** (*in millimeters*)

Univ. Calif. Coll.	Height of crown	Anteroposterior diameter	Transverse diameter
Type:			
Maxillary			
No. 19840			
Dp$\underline{3}$	....	12.4	13.5
Dp$\underline{4}$	....	12.8	....
M$\underline{1}$	....	13.0	....
Paratype:			
Ramus			
No. 19764			
P$\overline{4}$	9.5	14.1	10.5
M$\overline{1}$	....	13.6	8.8
M$\overline{2}$	....	*a*13.1	8.5

Length from anterior end of root of P$\overline{2}$ to posterior end of M$\overline{2}$, 74.0.

a, Approximate.

* Difference between these measurements and those given by Merriam may be due to slightly different systems of measurements.

In addition to the occurrences of *A. mourningi* in the Barstow and in the Merychippus zone, this species is now known from a third locality in California.

The major portion of a mandible with the lower dentition lacking only M$\overline{2}$ and M$\overline{3}$ on the left side, No. 12244 U. S. Nat. Mus. Coll., collected by Dr. C. L. Gazin in Miocene beds of Cajon Pass, San Bernardino County, California, is here referred to *Archæohippus mourningi.* This specimen is shown on Plate 5. Dr. Gazin has kindly furnished the following description of the locality:

> "The specimen was found in place in the southeast wall of the 2d railroad cut southwest of Alray. Alray is a small station at the intersection of the upbound track of the Santa Fe R. R. and the state highway in the upper part of Cajon Pass. The occurrence of this form along with the lower teeth of a larger merychippine form was just a few feet from a derail switch signal. The beds at this horizon are rather brightly colored, principally reddish brown and green. Although the *Archæohippus* jaw was found in the coarser red beds, both the reddish and greenish horizons exhibit bone fragments at other localities. Referring to the Hespina Quadrangle, the locality is in the W part of NW¼ sec. 26, T 3 N, R 6 W, S. B. B. & M."

The characters of the cheek-teeth in No. 12244 have been in large measure destroyed by wear. A very faint notch on the crowns of M$\overline{2}$ and M$\overline{3}$ of the right side indicates that a separation of the metaconid-metastylid column probably existed at an earlier stage of wear. There is no indication of an external cingulum on any of the teeth. The entostylid of M3̄ is conical in shape and is similar to that found in third lower molars of *Archæohippus mourningi* from the Merychippus zone. The greatest transverse diameter for the cheek-tooth series obtains across the posterior portion of P4̄. The paraconid of P2̄ is placed anteriorly to the metaconid rather than to the protoconid as in Dp2̄ of *A. penultimus.* The protoconid-hypoconid valley has the primitive backward slope. P1̄ is double-rooted. The crown forms a single ridge and is almost trenchant in aspect. This tooth is almost identical with a first premolar assigned to *A. mourningi* from north Coalinga. The symphyseal region of the jaw is larger and heavier than that found in the referred specimen of *A. penultimus,* but this difference may be due to the much greater age of the individual represented by No. 12244. The enamel walls of the teeth are smooth. All of the teeth are uncemented.

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[1] J. C. Merriam, *op. cit.*, 427–434, 1913.

[2] H. F. Osborn, *op. cit.*, 1918.

Measurements of No. 12244 U. S. N. M. (in millimeters)

	Anteroposterior diameter		Transverse diameter	
	Right	Left	Right	Left
P1̄	9.8	9.9	3.9	3.9
P2̄	13.2	12.8	7.5	7.9
P3̄	11.1	11.7	7.6	8.2
P4̄	11.5	11.4	8.8	9.3
M1̄	10.9	11.8	9.0	9.5
M2̄	11.8	....	9.0	....
M3̄	14.0	....	7.7	....

Length from incisor alveolar border to posterior side of M3̄, 124.7.
Length of tooth row P1̄–M3̄ inclusive, 83.9.

Parahippus sp.

A portion of a left ramus with Dp3̄–4̄ and P3̄–4̄, No. 23852 Univ. Calif. Coll., described by Maxson[1] as *Parahippus? (Archæohippus)* near *mourningi* Merriam from the Mint Canyon beds, California, is here referred to *Parahippus* sp. The specimen presents few diagnostic characters. The separation of the metaconid-metastylid column in the permanent teeth is less than that which one would expect to find in a parahippine form from the upper Miocene. The teeth are considerably larger than those of any known species

Measurements of No. 23852 Univ. Calif. Coll. (in millimeters)

	Height of crown	Anteroposterior diameter	Transverse diameter
Dp3̄	....	15.7	....
Dp4̄	....	17.7	....
P3̄	15.7	16.8	10.7
P4̄	15.8	16.7	11.2

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[1] J. H. Maxson, Carnegie Inst. Wash. Pub. No. 404, 91–92, fig. 5, a-d, 1930.

of *Archæohippus.* A calcareous deposit in the lingual valleys of $P\overline{3}$–$\overline{4}$ may represent cement. If this is the case, the specimen undoubtedly belongs to the genus *Parahippus.* An appearance of better material is desirable before the relationships of this form are more accurately defined.

Material Referred by Matthew[1] to Archæohippus from the Pawnee Creek Beds at Cedar Creek, Colorado

This specimen is a fragment of a left ramus with $M\overline{2}$ and $M\overline{3}$, No. 6305 Amer. Mus. Coll. $M\overline{2}$ is moderately worn. With the exception of a slight amount of wear on the paraconid-protoconid ridge, $M\overline{3}$ is unworn. This form is larger than any described species of *Archæohippus.* The metaconid is pointed with no indication of a metastylid. With the exception of an antero-external basal ridge on $M\overline{3}$, there is no indication of an external cingulum. The entostylid is loph-like and not conical as in *Archæohippus.*

This specimen differs from *Archæohippus* in greater size, in the absence of any separation of the metaconid-metastylid column, and in the loph-like development of the entostylid of $M\overline{3}$. These differences are sufficient to indicate that No. 6305 differs generically from *Archæohippus.* Possibly No. 6305 belongs to *Hypohippus.*

Measurements of No. 6305 (in millimeters)

	Anteroposterior diameter	Transverse diameter
$M\overline{2}$	13.8	9.7
$M\overline{3}$	19.5	9.5

Length from anterior end of $M\overline{2}$ to posterior end of $M\overline{3}$, 33.3.
Thickness of ramus below $M\overline{2}$, 13.3.

GENERIC STATUS OF ARCHÆOHIPPUS

Matthew[2] is inclined to regard *Archæohippus* as a sub-genus under the genus *Parahippus* for the following reasons:

1. Teeth in these two forms have in common:
    - *a.* Rugosity of enamel walls.
    - *b.* Broken protoloph.
    - *c.* Separate protocone.
    - *d.* Similar separation of the metaconid-metastylid column.
    - *e.* Unreduced $M\frac{3}{3}$.
2. Metatarsal like that of small *Parahippi* and of *Merychippus primus* in that the inner cuneiform has no footing on its head, while in *Anchitherium, Kalobatippus, Hypohippus, Equus, Pliohippus,* and in the European hipparions the metatarsal has a well-developed facet for the inner cuneiform.

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[1] W. D. Matthew, *op. cit.*, 1924.

[2] Amer. Mus. Novit. No. 540, 1932.

3. The shafts of the lateral metatarsals are reduced about as in *Parahippus pristinus*, rather less than in *Merychippus primus*, and the cross-section of the shaft is round-oval as in the protohippine horses generally (including *Parahippus*) in contra-distinction to the anchitheriine horses in which it retains the flat form of *Mesohippus*.
4. The phalanges are moderately elongated as in *Parahippus* and the protohippine horses, in contrast to the very short wide and flattened phalanges of the anchitheriine horses (including *Mesohippus*).

The *Archæohippus* material obtained in the Merychippus zone, together with additional specimens now available from other localities, establish more clearly the true taxonomic position of this genus. While the teeth of *Archæohippus* possess several characters common also to *Parahippus*, the three species of the former genus present a number of closely related characters sufficient to keep these forms in a distinct group. *Archæohippus* differs from *Parahippus* in the following characters: (1) Complete absence of a crochet, (2) constant thin and straight alignment of protoloph and metaloph, (3) precocious development of crown-height relative to small size of tooth, (4) complete absence of cement, and (5) peculiar and characteristic development of the preorbital fossa as shown in *A. ultimus* and in *A. penultimus*.

Matthew's objections to the generic status of *Archæohippus* appear to be somewhat overstressed. The rugosity of the enamel walls of a tooth has no diagnostic value whatsoever since this surface feature is found in teeth of practically all anchitheriine horses and also in the milk teeth of *Merychippus*. In all the upper teeth examined, the protoloph is usually sharply constricted between the protoconule and the protocone, but not one specimen has been found in which the protocone has been actually separated from the anterior transverse loph. The separation of the metaconid-metastylid column in *Archæohippus* is less than that found in contemporaneous species of *Parahippus*. Three specimens representing the third upper molar of *Archæohippus mourningi* collected in the Merychippus zone show that this tooth in the former species is distinctly reduced. Thus the genus, while primitive in many respects, presents certain characters in which it exhibits a progressive development. Lastly, the maximum transverse diameter for the cheek-tooth series occurs in $P\frac{4}{4}$, an advance beyond the position in which this measurement is found in typical members of the anchitheriine group.

A facet on the metatarsal for the inner cuneiform occurs in so many members of the Equidæ, as observed by Matthew, that it appears to have no generic value. The shape of the metatarsal shaft and of the phalanges, based on a young individual whose milk teeth are but slightly worn, are hardly characters of generic importance.

In view of the differences enumerated above it seems to the writer that *Archæohippus* may well be retained as a genus distinct from *Parahippus.*

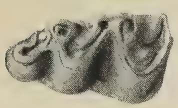
PLATE 1

FIGS. 1–5a.—*Parahippus brevidens* Marsh. Fig. 1, $M\overline{3}$, No. 1152; fig. 2, $M\overline{1}$?, No. 1143; fig. 3 $Dp\overline{3}$, No. 1149; fig. 4, $M\overline{1}$?, No. 1141; fig. 5, $P\overline{4}$, No. 1142. Merychippus Zone, California.

FIGS. 6–9.—*Hypohippus* sp. Fig. 6, $P\overline{2}$, No. 886; fig. 7, $P\overline{4}$?, No. 887; fig. 8, $M\underline{1}$, No. 885; fig. 9, $P\overline{3}$, No. 888. Merychippus Zone, California.

FIGS. 10–18.—*Parahippus brevidens* Marsh. Fig. 10, $M\underline{3}$, No. 1150; fig. 11, $M\underline{3}$, No. 1161; fig. 12, $P\underline{4}$, No. 406; fig. 13, $M\underline{3}$, No. 407; fig. 14, $P\underline{2}$, No. 1148; fig. 15, $M\underline{1}$?, No. 1145; fig. 16, $M\underline{1}$?, No. 1144; fig. 17, $P\underline{4}$, No. 1147; fig. 18, $M\underline{2}$?, No. 1146.

Nos. 1144, 1145, 1146, 1147, 1148, 1150, and 1161 from Merychippus Zone; Nos. 406 and 407 from Mascall middle Miocene, Oregon. All figures natural size. Calif. Inst. Tech. Coll.



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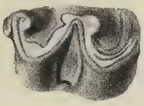

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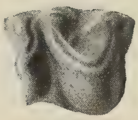

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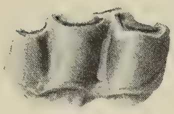

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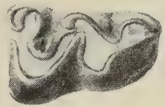

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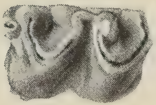

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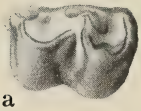

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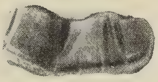

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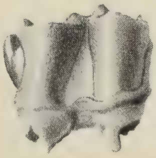

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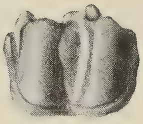

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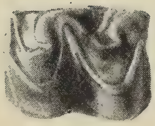

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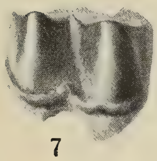

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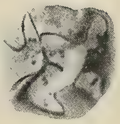

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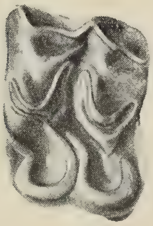

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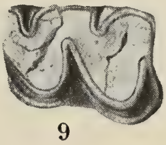

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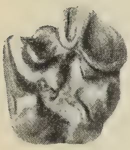

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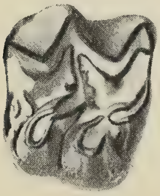

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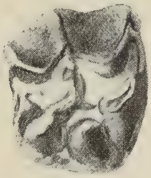

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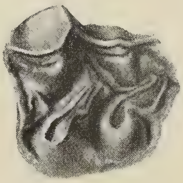

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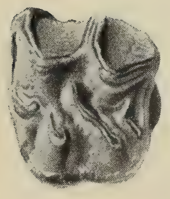

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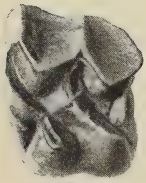

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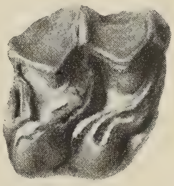

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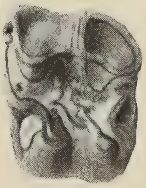
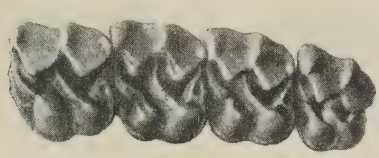


18

Plate 2

Figs. 1–5.—*Archæohippus mourningi* (Merriam). Fig. 1, composite series $P\underline{4}$–$M\underline{3}$, No. 881; fig. 2, $M\overline{3}$, No. 884; fig. 3, $Dp\underline{3}$, No. 883; fig. 4, $M\underline{3}$, No. 882; fig. 5, left ramus with $P\overline{3}$–$M\overline{3}$, No. 484. Merychippus Zone, California. All figures natural size. Calif. Inst. Tech. Coll.



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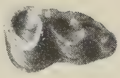

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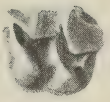

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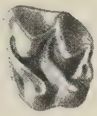

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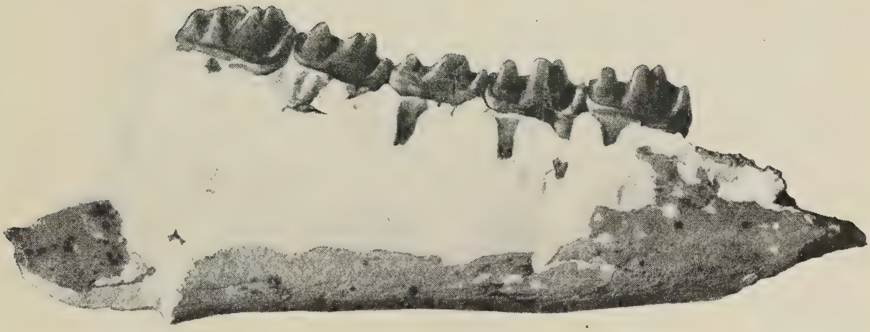

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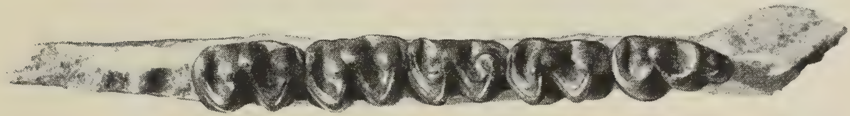

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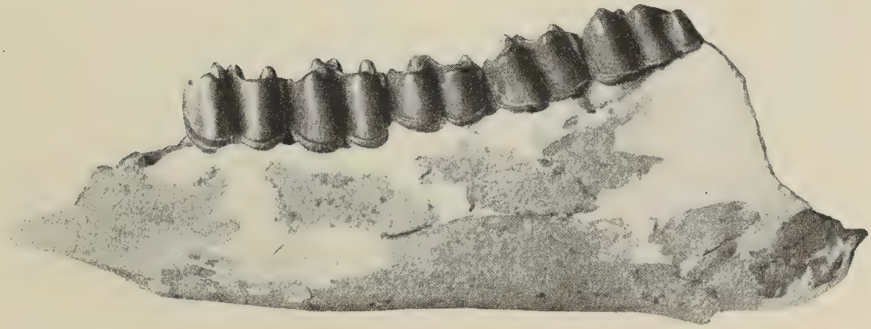


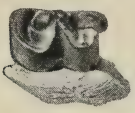
5^b

Plate 3

Figs. 1–4.—*Archæohippus ultimus* (Cope). Fig. 1, inferior molar, No. 3059; fig. 2, inferior molar, No. 424; fig. 3, inferior molar, No. 31987; fig. 4, M$\underline{3}$, paratype, No. 1689. Mascall middle Miocene, Oregon.

Figs. 5–6.—*Archæohippus mourningi* (Merriam). Fig. 5, type, portion of maxillary with Dp$\underline{3}$–Dp$\underline{4}$ and M$\underline{1}$, No. 19840; fig. 6, paratype, portion of ramus with dentition representing P$\overline{2}$–M$\overline{2}$, No. 19764. Barstow upper Miocene, California.

Nos. 3059, 1689, 19840, 31987, and 19764 from Univ. Calif. Coll.; No. 424 from Calif. Inst. Tech. Coll. All figures natural size.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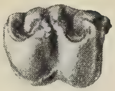
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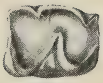
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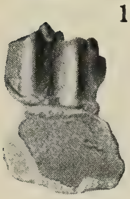
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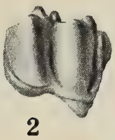
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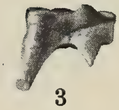
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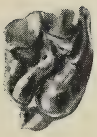
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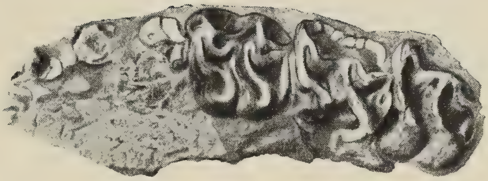
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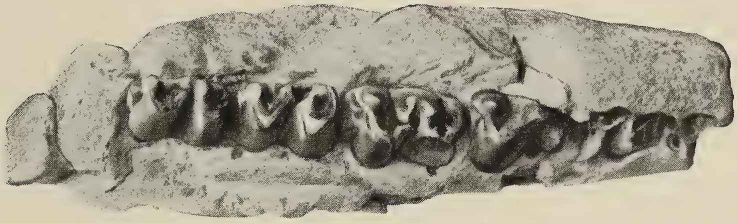
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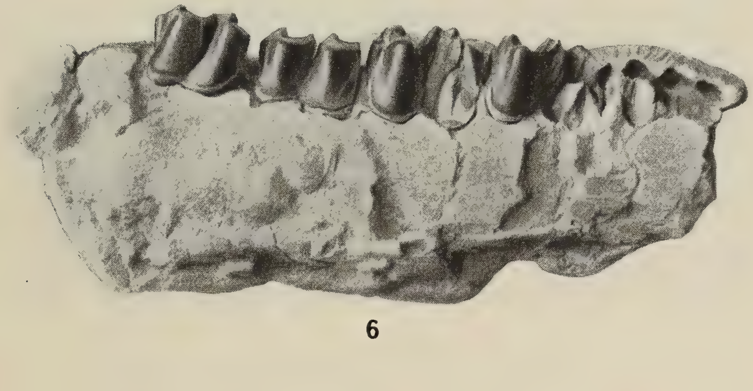
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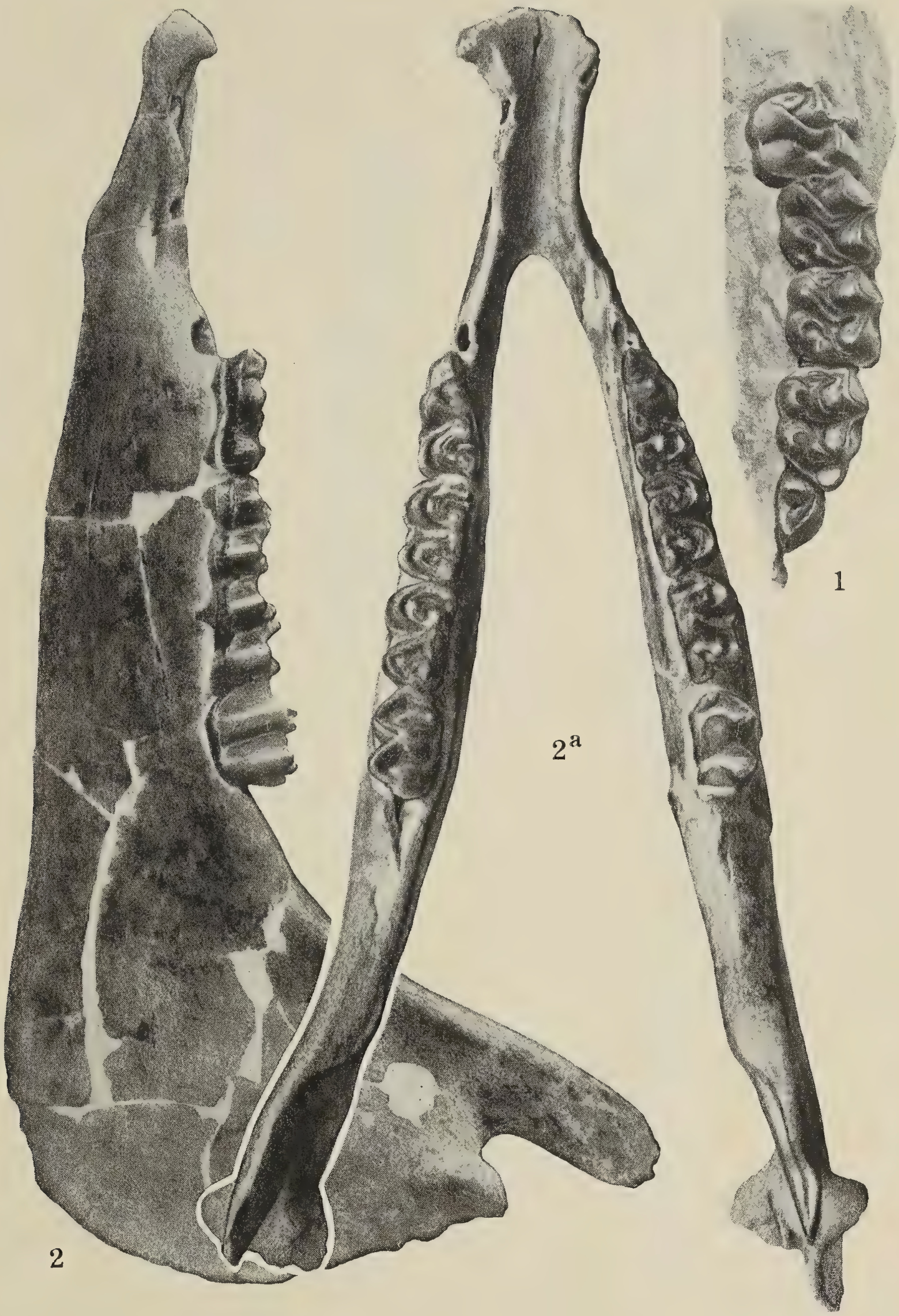
PLATE 4

Archæohippus penultimus Matthew. Fig. 1, palate, Amer. Mus. No. 21534. Figs. 2-2a, mandible, Amer. Mus. No. 21532; lateral and superior views; natural size. Lower Sheep Creek beds in Aphelops Draw, Sioux County, Nebraska.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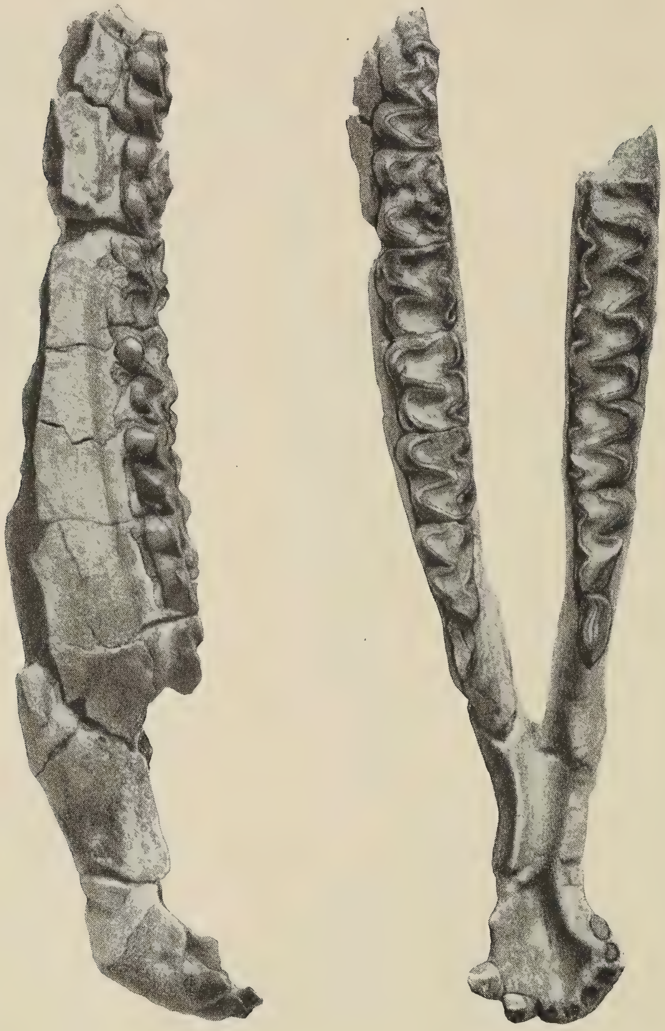

Archæohippus mourningi (Merriam). Mandible, U. S. Nat. Mus. No. 12244; lateral and superior views; natural size. The symphyseal end has been displaced upward in this specimen. Miocene beds in Cajon Pass, San Bernardino County, California.

VI

PLEISTOCENE MAMMALIAN FAUNA FROM THE CARPINTERIA ASPHALT

By Robert W. Wilson

[Issued November 1933]

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THE PLEISTOCENE MAMMALIAN FAUNA FROM THE CARPINTERIA ASPHALT

INTRODUCTION

Plant and animal remains were first discovered in the Carpinteria asphalt deposits on the Higgins Ranch near the town of Carpinteria early in 1927.[1] A preliminary announcement of the occurrence was published by Hoffman, Stock and Chaney.[2] Since then more detailed work carried on at the locality has furnished additional and larger collections of bird and mammal material. While the bird assemblage has been determined by Loye Miller[3] and by Alden Miller,[4] no very complete list of the mammals is as yet available. The present study embodies a critical determination of the various mammalian types occurring in the fauna with a view to establishing evidence of value in an interpretation of the age relationships of the deposits and of the environmental conditions under which the mammalian fauna existed. The problem was suggested by Doctor Chester Stock of the California Institute of Technology, to whom the author is indebted for guidance during the course of the investigation and for criticism of the manuscript.

The author also wishes to thank the staff of the late Mr. Donald R. Dickey at the California Institute of Technology for courtesy in permitting use of their collections of Recent mammals.

CHARACTER AND AGE OF FAUNA

The mammalian material from Carpinteria is of very fragmentary character. Due to the incomplete preservation, specific identification of the remains was always difficult and for most of the types only a generic determination was possible. Moreover, a satisfactory determination of the material was not always reached because of the immaturity of a large number of individuals entombed in the tar. While the rodent assemblage is not characterized particularly by immature animals, 50 per cent or more of the remaining material in the collection represents animals which range in age from juvenile to sub-adult. Among the larger mammals, as for example the dogs, deer and horses, this aspect of the fauna is carried to such an extreme that practically no remains of adults are found. The following is a list of mammals occurring in the Carpinteria asphalt.

---

[1] Evidently the first notice of wood impregnated by bitumen occurring in deposits exposed on the Higgins Ranch was made by H. C. Ford in Bull. Santa Barbara Soc. Nat. Hist., vol. I, No. 2, 11, 1890.

[2] Science, vol. 66, 155–157, 1927.

[3] Loye Miller, Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 20, 361–374, 1931.

[4] A. H. Miller, Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 21, 169–194, 1932.

- Insectivora
  - Sorex cf. ornatus Merriam
  - Sorex cf. trowbridgii Baird
- Carnivora
  - Mustela species
  - Spilogale phenax Merriam
  - Mephitis occidentalis Baird
  - Taxidea species
  - Urocyon near cinereoargenteus (Schreber)
  - Canis species
  - Ænocyon near dirus (Leidy)
  - Felis probably atrox Leidy
  - Lynx species
- Artiodactyla
  - Camelops? cf. hesternus (Leidy)
  - Odocoileus species
  - Bison? species
- Rodentia
  - Eutamius species
  - Sciurus species
  - Thomomys near bottæ (Eydoux and Gervais)
  - Perognathus species
  - Dipodomys species
  - Onychomys? species
  - Peromyscus species
  - Neotoma species
  - Microtus californicus (Peale)
- Lagomorpha
  - Lepus near californicus Gray
  - Sylvilagus bachmani (Waterhouse)
- Perissodactyla
  - Equus near occidentalis Leidy

The presence of many forms closely similar in structural details to living species now occupying the region of Carpinteria suggests an age of the fauna not older than Quaternary. The mammalian assemblage includes only four extinct types, namely, *Ænocyon* near *dirus*, *Felis* probably *atrox*, *Camelops?* cf. *hesternus* and *Equus* near *occidentalis*. *Sorex* cf. *trowbridgii*, *Onychomys?* species, and *Bison?* species, do not now range in the area about the brea deposits. The remaining mammals in the fauna, so far as they can be determined, do not differ from those existing in the region at the present time. Thus the constituency of the Carpinteria assemblage offers no salient facts mitigating against a late Pleistocene age.

Comparison with the mammalian fauna of Rancho La Brea does not satisfactorily establish the age relationship of the Carpinteria assemblage with reference to the former. The occurrence at Carpinteria of a few forms which do not appear at Rancho La Brea may be due to a difference in ecologic conditions. The presence at both localities of a number of Recent genera sheds no light on the respective ages of the deposits. Thus some of the principal evidence of value in determining the time relationships of the two faunas is presented by the absence at Carpinteria of many of the extinct forms that occur commonly at Rancho La Brea. It should be emphasized, however, that this is negative evidence, doubtless magnified somewhat by the difference in ecologic conditions prevailing at the two localities. On the other hand the presence of species evidently related to *Ænocyon dirus*, *Felis atrox*, *Camelops hesternus* and *Equus occidentalis* at Carpinteria may be regarded as evidence suggesting that the fauna was contemporaneous with the Rancho La Brea assemblage. The conclusion may be drawn from these considerations that the Carpinteria fauna is certainly not older than the assemblage from Rancho La Brea, and may be younger.

ECOLOGIC CONSIDERATIONS

In determining the ecologic aspects of the Carpinteria occurrence as inferred from the mammalian fauna, the presence of shrews is significant for, according to Hartley H. T. Jackson,[1] these insectivores characteristically inhabit moist places with abundant vegetation, such as stream banks, meadows and damp woods, especially of coniferous trees. *Sorex trowbridgii* offers a slight deviation, for although found at the present time in the habitat usually occupied by the long-tailed shrews, it shows a marked tendency to inhabit drier woods. Thus the occurrence of shrews in the Carpinteria asphalt furnishes an item of evidence in support of the forest environment postulated from a study of the avifauna and of the flora.

Rodents are in general sensitive indicators of climate and environment. While the fragmentary state of preservation of the material makes an interpretation of the ecologic conditions difficult, the evidence presented by these mammals may serve to check, and perhaps amplify, conclusions drawn from studies of the birds, plants and other mammals.

Presence of the chipmunk (*Eutamius*) and of the tree squirrel (*Sciurus*) suggests rather strongly a region at least partly forested, and is thus evidence again substantiating conclusions derived from a study of the avifauna and of the flora. The list of rodents and lagomorphs moreover indicates a mingling of semi-arid and sylvan types. Associated with *Sciurus* and *Eutamius* are *Dipodomys* and *Onychomys?*. Doctor Loye Miller[2] records evidence for the recognition of two ecologic stages during the period of occurrence of the Carpinteria avifauna, but does not regard this difference as necessarily due to a major time interval. Doctor Miller believes both stages show a definite sylvan environment with one faunule exhibiting this character more strongly than the other. This view does not satisfactorily explain the relationships found in the rodent fauna. The intermingling of semi-arid and sylvan forms in the same deposits may, however, be accounted for if we assume that the accumulation of the material occurred at a locality situated near the edge of an existing forest.

When compared with the Pleistocene rodent fauna from Rancho La Brea, the Carpinteria assemblage exhibits some marked differences. Presence of the chipmunk and tree squirrel at Carpinteria and their absence at Rancho La Brea support the evidence furnished by the floras and avifaunas that the region was, unlike that in the vicinity of Rancho La Brea, at least partly forested. Further, the relative abundance of individuals representing different genera offers some contrasting features. At Rancho La Brea gophers of the genus *Thomomys* far exceed all other forms in numerical representation. Among the rodents and lagomorphs found at the latter locality those relatively abundant in the fauna are the kangaroo-rat *Dipodomys*, the pocket-mouse *Perognathus*, and the cottontail *Sylvilagus audubonii*, while those less abundant include the meadow-mouse *Microtus*, the white-footed mouse or deer-mouse *Peromyscus*, and the ground-squirrel *Otospermophilus*. Rare forms are represented by the harvest-mouse *Reithrodontomys*, the jack-rabbit *Lepus*, the brush-rabbit *Sylvilagus bachmani*, the wood-rat *Neotoma*, and the grasshopper-mouse *Onychomys*. In the Carpinteria asphalt, *Peromyscus* occurs as the most abundant form. The deer-mice are represented by more than twice the number of individuals recorded for the type nearest in abundance. With decreasing representation, but still abundant, occur the genera *Dipodomys*, *Thomomys* and *Microtus*. *Eutamius* and *Sylvilagus bachmani* are relatively common while *Perognathus*, *Sciurus*, *Onychomys?*, *Neotoma* and *Lepus* are rare. The order of abundance may or may not possess significance as a reflection of differences in ecologic conditions presented at the two localities. It is well to remember that the susceptibility of certain forms to capture by the peculiar agencies operative in tar seep accumulations may be responsible for at least some of the difference in numerical representation. The presence of a relatively large number of individuals of the genus *Dipodomys* is interesting, since this form occurs typically on arid and semi-arid plains of the Californian region at the present time. Assuming that the fundamental habits and habitat of the kangaroo-rats have undergone no great change since late Pleistocene time, the occurrence of these creatures at Carpinteria furnish some of the more striking evidence in support of the view that the forest cover in the region of the asphalt accumulation was broken by areas of sparser vegetation.

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[1] Hartley H. T. Jackson, U. S. Dept. Agriculture, North American Fauna No. 51, 3–4, 1928.
[2] Loye Miller, *ibid.*, 364–365, 1931.

A minimum number of 130 individuals is represented in the rodent and lagomorph fauna. Approximate percentages of individuals for particular genera are as follows:

Sciuridæ
    Eutamius, 5 per cent
    Sciurus, 1 per cent

Geomyidæ
    Thomomys, 16 per cent

Heteromyidæ
    Perognathus, 2 per cent
    Dipodomys, 17 per cent

Cricetidæ
    Onychomys?, 1 per cent
    Peromyscus, 39 per cent
    Neotoma, 1 per cent
    Microtus, 12 per cent

Leporidæ
    Lepus, 1 per cent
    Sylvilagus, 5 per cent

Presence of the larger mammals likewise suggests an environment not exclusively sylvan in character. While a number of these forms may have lived under forest conditions, *Equus*, *Bison* and *Camelops* appear to reflect the influence of more open country and of a semi-arid climate.

Thus a survey of the fauna reveals the presence of certain mammals whose inferred habits and habitats substantiate the ecologic conditions at the Carpinteria locality postulated from a study of the plants and avifauna found in the asphalt. In addition to these are other mammals that normally inhabit semi-arid regions. Presence of the latter appears to reflect an influence which is not so apparent from the constitution of the plant or avian assemblage. Proximity of the locality of occurrence to a forest border with perhaps fluctuations in the amount and extent of the plant and tree cover during the period of accumulation may account for this association of mammals.

Furthermore, the presence of many young and immature individuals among the mammals suggests likewise (1) a particularly great susceptibility to entombment in brea deposits, in which respect the Carpinteria fauna may be likened to the Rancho La Brea assemblage, and (or) (2) opportunities for shelter and protection afforded by tree and plant cover.

DESCRIPTION OF FAUNA

INSECTIVORA

Sorex cf. ornatus Merriam

Remains of this long-tailed shrew are limited to two right rami, one with complete dentition excepting the lower canine, No. 32.1 Santa Barbara Museum Pale. Coll., the other without teeth. As far as can be determined, these rami represent the same species.

Size and geographic distribution of species inhabiting western California are of particular importance in the attempt to reach a determination of this insectivore. Shrews do not exhibit much individual variation in size, nor is there a great sex difference in this character. No species other than *S. ornatus* is now found in the Carpinteria region, and the fossil specimens agree well in size and in tooth structure with this form. Certain subspecies of *S. obscurus* and *S. vagrans* are similar in size to *S. ornatus*. While not occurring in the Carpinteria region at the present time, the distribution of these types is such that their range during the Pleistocene may have included also this area. Definite specific determination must await, therefore, the acquisition of more complete material.

Sorex cf. trowbridgii Baird

A single specimen of this type is available, a portion of maxillary bearing P$\underline{4}$ to M$\underline{2}$, No. 32.2 Santa Barbara Mus. Pale. Coll. The fossil specimen corresponds in size and in tooth structure to *Sorex trowbridgii montereyensis* and evidently differs distinctly from *S. ornatus* in larger size.

The Carpinteria specimen is smaller than *S. pacificus sonomæ* and evidently larger than *S. vagrans halicœtes*. The latter subspecies is restricted to a limited area immediately south of San Francisco Bay. The Carpinteria form presumably is also larger than *S. obscurus obscurus* from the Sierran region and *S. o. parvidens* from the San Bernardino Mountains. No direct comparisons were made, however, with the three last-mentioned forms.

Sorex t. montereyensis does not at the present time extend southward into the Carpinteria region, although it is found in Santa Barbara County and may have had an even greater range in the Pleistocene.

CARNIVORA

Mustela species

Only one specimen of a weasel has thus far been obtained. This is a skull fragment representing the occipital segment, tympanic bullæ, and portions of the parietal, No. 1275, Calif. Inst. Tech. Coll. Vert. Pale.

In size No. 1275 falls within the range of the California weasel *Mustela xanthogenys.* The tympanic bullæ do not seem to be so truncate anteriorly as in typical *M. xanthogenys.* However, according to C. Hart Merriam[1] the tympanic bullæ in *M. xanthogenys* are usually truncate anteriorly, a statement implying that variations exist in this character.

Spilogale phenax Merriam

Remains of the spotted skunk are distinctly less common in the collections than those of the striped skunk. The material consists of two skulls, Nos. 1276 and 1277, and a ramus, No. 1278, Calif. Inst. Tech. Coll. Vert. Pale. Specimen No. 1276 is a nearly complete adult skull lacking only the dentition anterior to P$\underline{3}$ on each side. No. 1276 may represent a female individual. Specimen No. 1277 is an incomplete skull of an adult, possibly female, which is fractured across the postorbital processes and with the occipital region missing and zygomatic arches incomplete. Right M$\underline{1}$ is missing as is the dentition anterior to P$\underline{3}$ on either side. Specimen No. 1278 is a rather large, perfect left ramus with M$\overline{1}$ to $\overline{\text{C}}$ in place. The two skulls do not differ essentially from each other except in minor details and these may be regarded as manifestations of individual variation.

Intergrades between subspecific types of skunks whose ranges extend well away from the Santa Barbara area are known to occur in this region at the present time. Assuming that the zone of intergradation has undergone no profound shift since the period of occupancy of the Carpinteria Pleistocene fauna, one might expect to find *Spilogale* in the latter assemblage exhibiting likewise the characters of intergrades. If on the other hand the Monterey forest assemblage during Pleistocene time extended southward into the Santa Barbara region, a representation of the northern skunk (*Spilogale phenax phenax*) in the asphalt appears entirely probable. It is also conceivable that the race, *Spilogale phenax amphialus,* inhabiting the Channel Islands, might represent in at least some of its subspecific characters the type found in the Carpinteria Pleistocene.

Although these considerations hold much of interest in the identification of fossil spotted skunks from the asphalt, definite assignment of the latter to any one of the living subspecies can hardly be countenanced in the absence of larger series of specimens. Moreover, the fossil material, as best exemplified in No. 1276, possesses a combination of characters which makes it difficult to place in any one of the three Californian subspecies, namely *phenax, microrhina* and *amphialus.* If specimen No. 1276 represents a female, then this difficulty is certainly not diminished. If on the other hand No. 1276 is a male the specimen resembles more the southern form, *S. p. microrhina,* than either *phenax* or *amphialus.*

Perforation of the skull in the region of the postorbital constriction, due to the work of parasitic larvæ and frequently found in the Recent *Spilogale,* is present also in the fossil, No. 1276.

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[1] C. Hart Merriam, U. S. Dept. Agric., North American Fauna 11, 25, 1896.

Mephitis occidentalis Baird

Remains of the striped skunk are numerous in the Carpinteria deposits. The material includes fragments of skulls and more or less complete lower jaws as well as two fairly complete skulls, No. 32.3 Santa Barbara Mus. Pale. Coll., and No. 1279, Calif. Inst. Tech. Coll. Vert. Pale. No. 32.3 S.B.M. is in a nearly perfect state of preservation but lacks P$\underline{2}$ to I$\underline{2}$ on the right side and all of the teeth anterior to P$\underline{4}$ on the left side. The specimen apparently represents a fully adult, but not old, female. Specimen No. 1279 is a fairly complete skull of an adult male. I$\underline{1}$ to $\underline{\mathrm{C}}$ are missing on the left side, as are the teeth anterior to P$\underline{3}$ on the right side. The skull is fractured transversely across the postorbital constriction and part of the zygomatic arch is broken away.

A study of the fossils indicates that the material is evidently to be placed in the *occidentalis* group. Certain characters which are exhibited tend to separate the Carpinteria form from *Mephitis occidentalis occidentalis* and *M. o. holzneri.*

Specimen No. 32.3 Santa Barbara Mus. when compared with female skulls of *M. o. occidentalis* available for comparison shows the following differences: foramen magnum more elliptical; auditory and mastoid bullæ more inflated; and M$\underline{1}$ and P$\underline{4}$ weaker. The most striking difference is seen perhaps in the shortened anteroposterior diameter of M$\underline{1}$. This tooth in Recent specimens is heavier and more nearly square.

M. o. holzneri in contrast to *M. o. occidentalis* is characterized principally and perhaps only by smaller size throughout. This is shown by the measurements given by Howell[1] as well as by measurements of specimens in the Dickey collection. Specimen No. H959 in the latter collection, for example, is smaller throughout, in spite of the fact that it is a very old female with cranial sutures completely obliterated and with very well-worn teeth. Compared to *M. o. holzneri,* No. 32.3 of the Santa Barbara Museum collection is also larger throughout. The auditory and mastoid bullæ are more inflated, although this difference is less pronounced; the brain-case is flatter; and the external nares narrower. The ratio of the anteroposterior diameter to the transverse diameter in M$\underline{1}$ is less than in No. H959. This is also the case when comparison is made between the Carpinteria form and *M. o. occidentalis.*

Thus specimen No. 32.3 approaches *M. o. occidentalis* in size, but differs from this form and approaches *M. o. holzneri* in several characters. Certain of the distinctive features seen in No. 32.3 are not so evident or are absent in No. 1279 C.I.T. In the several specimens available from the asphalt, two characters appear to distinguish the fossil type from existing subspecies of western California, namely, (1) anteroposterior shortness of M$\underline{1}$ and (2) slenderness of M$\underline{1}$ and P$\underline{4}$.

Taxidea species

A single calcaneum represents the identifiable remains of a badger in the Carpinteria fauna. This specimen can not be distinguished from Recent calcanea and approximates in size the comparable element in *Taxidea taxus berlandieri.*

Urocyon near cinereoargenteus (Schreber)

Remains indistinguishable from the California gray fox are fairly common in the brea deposits. Unfortunately the material consists for the most part of scattered limb elements. Four incomplete rami are also present, two of which belong to juvenile individuals. Most of the teeth in these rami are missing. Specimen No. 1280 Calif. Inst. Tech. Coll. Vert. Pale., a left ramus, bears $P\overline{2}$ and an incomplete $P\overline{3}$. Specimen No. 1281 Calif. Inst. Tech. Coll. Vert. Pale., also a left ramus, has $P\overline{2}$ and $P\overline{3}$ in place. Specimens Nos. 1282 and 1283 Calif. Inst. Tech. Coll. Vert. Pale. are rami of juvenile individuals, each bearing $Dp\overline{3}$. In addition, an isolated lower milk carnassial is evidently to be referred to the fox.

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[1] A. H. Howell, U. S. Dept. Agric., North American Fauna 20, 44, 1901.

Existing foxes of the genus *Urocyon* in the Californian region include the characteristic species of the Channel Islands, and the mainland race *Urocyon cinereoargenteus californicus.* The island forms are all noticeably smaller than the mainland species if comparisons are made between individuals of the same sex. The Carpinteria specimen No. 1280, the larger of the two adults, compares favorably in size with fully adult males of *U. c. californicus.* The smaller ramus, No. 1281, is comparable in size to a fully adult female or possibly a small male of the mainland form. This specimen is similar in size to adult males of the island species. The presence of the larger ramus suggests, however, that the species occurring in the asphalt is related to *U. cinereoargenteus.*

Canis species

The material referred to this genus includes a right ramus with $M\overline{2}$, No. 32.4 Santa Barbara Mus. Pale. Coll., of a coyote and various limb elements which may belong to either coyote or wolf. A definite determination of the latter remains is at present not practicable because of the immaturity of the bones.

Comparative measurements (in millimeters)

	Canis sp. No. 32.4 S. B. Mus. Carpinteria Pleistocene	*Canis ochropus* No. 13789 ♂ Dickey Coll. Recent	*Canis l. lestes* No. 14576 ♂ Dickey Coll. Recent
$M\overline{3}$–$P\overline{1}$, alveolar length	82.5	75.1	80.9
$M\overline{1}$–$M\overline{3}$, alveolar length	39.6	33.8	36.9
$P\overline{1}$–$P\overline{4}$, alveolar length	42.5	41.2	43.8
$M\overline{1}$, alveolar length	24.2	19.9	21.3
Length of diastema between $P\overline{1}$ and $\overline{C}$	2.0	7.0	6.1
$M\overline{2}$, anteroposterior diameter	10.5	9.8	10.8
$M\overline{2}$, transverse diameter	7.1	6.8	7.3

The ramus differs from that of *Canis ochropus*, the California Valley coyote, in slightly larger size, in the more crowded position of the premolars, and in the considerably longer carnassial as indicated by comparative measurements of the alveolus of $M\overline{1}$. The metaconid of $M\overline{2}$ is more pronounced in the Carpinteria specimen but this character is doubtless attributable to the unworn state of the crown of this tooth. The premolars of No. 32.4 are more crowded than in *Canis ochropus orcutti* from Rancho La Brea.

In the characters enumerated, No. 32.4 resembles *Canis latrans.* The only subspecies of *C. latrans* available for comparison, *Canis latrans lestes,* is intermediate in character between *Canis ochropus* and No. 32.4. However, *C. l. lestes* is not so large as typical *C. latrans,* and the carnassial and premolar teeth are smaller and less swollen. While *C. latrans latrans* may approach the Carpinteria specimen rather closely, specific identification of the latter form is hardly warranted on the basis of material available.

Although the limb elements of *Canis* from the Carpinteria deposits can not be specifically determined because of their immaturity, the larger number of these specimens appear to represent the coyote. The limb elements likewise indicate a slightly larger form than *Canis ochropus.*

An immature ulna, No. 1284 Calif. Inst. Tech. Coll. Vert. Pale., is somewhat larger than the comparable element in a fully adult male individual of *Canis ochropus.* This specimen may belong to a timber wolf. Two radii are very doubtfully referred to the same form or to a large coyote. Unfortunately no skeletons of young wolves are available for comparisons.

Ænocyon near dirus (Leidy)

Three specimens have been recognized as belonging to the dire wolf. Specimen No. 1285 Calif. Inst. Tech. Coll. Vert. Pale. represents a portion of a maxillary bearing Dp$\underline{3}$ and Dp$\underline{4}$. Specimen No. 1276 Calif. Inst. Tech. Coll. Vert. Pale. is a fifth metacarpal with distal epiphysis missing.

Specimen No. 1285 compares favorably with figures of the milk dentition of *Ænocyon dirus* (U. C. 10831) from Rancho La Brea given by Merriam.[1]

Comparative measurements (in millimeters)

	No. 1285 C.I.T. Carpinteria	No. 10831* Univ. Calif. Rancho L. Brea
Dm$\underline{3}$, greatest anteropost. diam.	14.8	14.6
Dm$\underline{4}$, greatest anteropost. diam.	10.8	10.8
Dm$\underline{4}$, greatest transverse diam.	12.1	11.4

* Measurements after Merriam.

Specimen No. 1286, although representing an individual which is not yet fully grown, compares favorably with *Ænocyon dirus* material from Rancho La Brea.

An additional specimen of the dire wolf in the collections of the Santa Barbara Museum, a fragment of maxillary bearing Dm$\underline{2}$ to Dm$\underline{4}$, furnished the basis for the determination of this form in the preliminary report on the Carpinteria occurrence.

Felis probably atrox Leidy

A fragment of ramus with milk carnassial, No. 1287 Calif. Inst. Tech. Coll. Vert. Pale., represents a cat which appears to be larger than either *Felis concolor* or *Felis onca.* No. 1287 compares favorably with the comparable milk tooth of *Felis leo* in size, and for this reason the Carpinteria specimen is tentatively referred to *Felis atrox* Leidy. A poorly preserved astragalus of an immature individual is tentatively determined as belonging to the Felidæ. The element is considerably larger than the comparable bone in the wildcat, but probably is not to be referred to the larger felid represented by the jaw fragment.

Lynx species

Two immature calcanea and an astragalus have been assigned to this genus. The astragalus is slightly larger than comparable specimens of *Lynx rufa californicus.* The calcanea are only slightly larger than the comparable element in an adult male domestic cat. However, since the specimens are not fully developed, they have been assigned tentatively to the wildcat.

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[1] J. C. Merriam, Mem. Univ. Calif., vol. 1, 233, figs. 12–13, 1912.

RODENTIA

Eutamius species

Several lower jaws and portions of palates establish the presence of the chipmunk. Characters in the dentition clearly indicate that the genus represented is *Eutamius*. The Eastern Chipmunk *Tamius* is at present so far removed in range from the Carpinteria locality as to further preclude the possibility of generic reference other than to *Eutamius*.

On the basis of size and of geographical distribution, the fossil species should apparently be assigned to the *townsendii* group. The subspecies inhabiting the Carpinteria region today is *Eutamius merriami merriami*. Whether the fossil form is to be included in this living species and subspecies can not be satisfactorily determined in view of the range in variation exhibited in the subspecies itself. Skull and jaws of an adult female in the Dickey collection, collected in a Recent fauna at Carpinteria, exhibit characters which are identical with those shown by the Pleistocene form except for slight differences due to varying amounts of wear. Careful examination of numerous specimens of the subspecies *Eutamius merriami merriami* demonstrates a marked variation in certain features of the dentition of this form and eliminates slight differences which might be regarded as of specific or sub-specific value.

Owing to the incompleteness of the fossil material and the minute morphological differences which distinguish the skulls and teeth of living chipmunks, it seems inadvisable to carry the identification of the Pleistocene type beyond the genus.

Sciurus species

The tree-squirrel *Sciurus* is represented in the Carpinteria assemblage by only two isolated teeth, $P\overline{4}$ and $M\overline{1}$?. These specimens agree in size and structure with comparable teeth in Recent specimens of *Sciurus griseus anthonyi* from Santa Barbara County. The teeth are low-crowned and with little or no elevation of the trigonid portion of the crown. The two anterior cusps of $P\overline{4}$ are situated close together, and their position gives a triangular shape to this tooth which is characteristic of *Sciurus*, *Otospermophilus* and *Ammospermophilus*. The California ground-squirrel *Otospermophilus beecheyi* approaches the fossil form in size, but is distinguished from it by slightly higher cusps and by the development of a distinct protoconid-hypoconid ridge.

Thomomys near bottæ (Eydoux and Gervais)

Specimens of the gopher *Thomomys* consist of numerous lower jaws, portions of the premaxillæ bearing the incisors, and the anterior portion of a skull with the complete upper dentition.

In the fossil specimens, the posterior enamel plate of the upper premolar is complete. The last upper molar has only two enamel plates, an anterior and a posterior one. The posterior enamel plate is present and complete on the first, second and third upper molars. Two enamel plates are also present on each of the lower molars. These characters identify the fossil form as *Thomomys*.

Comparison of the material with Recent species shows that the form from the Carpinteria asphalt is a representative of the heavy rostrum group which includes among others the following types; *T. bulbivorus*, *T. townsendii*, *T. bottæ, T. alpinus, T. perpallidus, T. fulvus, T. umbrinus.* The following distinctive characters can be observed in the skull of the fossil form:

1. Heavy rostrum
2. Upper incisors with very obscure groove, which may be absent in some specimens
3. Incisors slightly projecting
4. Large size
5. Nasals apparently spatulate.

In view of the enumerated characters, the fossil material has been compared with *T. bottæ.* This species has a very wide distribution at the present time and if *leucodon* is accepted as one of its sub-species, its distribution was equally wide during the Pleistocene. No specific characters in the fossil material serve to distinguish the asphalt species from Recent *T. bottæ.* The two forms correspond closely in size. An apparently immature individual from the asphalt is characterized by a skull with greater dorso-ventral diameter than in any Recent *T. bottæ* of comparable age. The skull characters of gophers vary so greatly with age that the difference noted above can hardly be regarded as sufficient evidence to distinguish specifically the fossil from the Recent type.

Until more material becomes available the gophers of the Carpinteria asphalt are referred, therefore, to *Thomomys bottæ.*

Perognathus species

The specimens of the pocket-mouse *Perognathus* consist of three rami, of which one retains the fourth premolar while the others are without teeth. The paucity of characters presented by this material does not permit positive specific determination.

The size of the lower jaws are within range of variation of jaws of *Perognathus californicus californicus,* and no characters are present to distinguish the fossil type from this subspecies. The generic determination is all that is advisable for the present.

Dipodomys species

The Carpinteria material comprises chiefly lower jaws, with a few maxillary fragments bearing teeth. The teeth of the kangaroo-rat *Dipodomys* present apparently few noteworthy specific characters, for they possess an extremely simple pattern. The expanded bullæ and mastoids, on which specific identification of skulls is frequently made, are unfortunately lost in the fossil specimens.

The specimens available agree in size with the corresponding structures in *Dipodomys agilis.* This species now lives in the vicinity of Carpinteria. However, no specific determination of the fossil material seems warranted.

Onychomys? species

A single left lower jaw without teeth is the only available material from Carpinteria which probably represents the grasshopper-mouse *Onychomys* in the collection. It is possible to distinguish this jaw from *Peromyscus* on the basis of the well-developed coronoid process as well as by the greater angle at which the ascending ramus meets the alveolar portion of the jaw.

The specimen can be distinguished from the lower jaw of *Reithrodontomys* by the character of the descending process of the ramus. In *Reithrodontomys* this portion of the ramus is bent into a more horizontal position than in *Onychomys* and the extreme edge is twisted upward, leaving a depression. Moreover, the coronoid process is less strongly developed in *Reithrodontomys.*

The ramus represents an individual of rather large size, but in this character the species lies within the range of size of *O. torridus* and within that of the subspecies *O. t. ramona.*

Peromyscus species

Remains of the deer-mouse *Peromyscus* consist of lower jaws, usually without teeth, and two maxillary fragments. One of the latter specimens bears $M\underline{1}$ and $M\underline{2}$ while the other carries only the second molar. Due to the scarcity and incompleteness of the material, no specific determination is made.

The pattern of the teeth is very simple and no accessory tubercles are present on any of the molars. On the basis of the latter character the material from the brea deposits may be referred to the subgenus *Haplomylomys.*

Individuals of the living Carpinteria type, *P. californicus californicus* and its related subspecies *P. c. insignis,* appear to be distinctly larger than the fossil forms. The subspecies *P. c. insignis* in contrast to *P. c. californicus* includes individuals of smaller size, and the fossil forms, although deviating somewhat from the norm in this character, may represent the latter subspecies. The Carpinteria asphalt species resembles also *P. eremicus,* another member of the subgenus *Haplomylomys.* At the present time *P. eremicus* does not range so far north as Carpinteria.

P. eremicus fraterculus is another subspecies exhibiting characters close to those of the fossil form in so far as the material permits of comparison. However, one or two differences are to be noted. In *P. e. fraterculus* the median anterior cusp is characterized, in a fairly unworn tooth, by a small infold. This is entirely absent in the fossil species or is only slightly indicated. This character is noted in some specimens of *P. c. insignis* and is absent in other specimens of the same subspecies.

The fossil specimens show the average angle formed by the anterior border of the ascending ramus and the alveolar border of the mandible to be greater than in Recent individuals of *P. e. fraterculus.* The reliability of this character is open to question.

Possibly two species of *Peromyscus* are present in the Carpinteria beds. Of the subgenera, *Peromyscus* has lower molars on which the accessory tubercles are sometimes poorly developed. Possibly some of the lower jaws found in the asphalt represent this subgenus, although no accessory tubercles can be observed on any of the molars. A representative of the subgenus *Peromyscus,* namely *P. maniculatus gambeli,* is found in the Carpinteria region today.

The Carpinteria fossil types may not represent any existing species of *Peromyscus,* and until better material becomes available there appears to be no special reason for assigning these forms to either a new or to an existing species.

The genus *Reithrodontomys* may be represented in the collection by numerous small jaws known to belong to cricetine rodents. The rami average smaller than those referred to *Peromyscus,* although a line of division based on size is difficult to establish. The specimens agree closely with jaws of *Reithrodontomys megalotis longicauda,* a form which inhabits the region about the Carpinteria deposits at the present time.

The principal character of generic importance in the mandible of *Reithrodontomys* is the shape of the descending process. A statement of the characters of this genus given by A. H. Howell is quoted in part.[1]

A. H. Howell, U. S. Dept. Agric., North American Fauna No. 36, 14, 1914.

"Descending process of mandible a broad flattened plate, strongly inflected inward, the lower portion twisted into a nearly horizontal position and the inner margin raised, leaving a distinct depression in the ramus . . ."

However, certain species of deer-mice belonging to the subgenus *Haplomylomys* show practically the same character. As members of the subgenus *Haplomylomys* are present in the Carpinteria assemblage, this character can be used only tentatively. The character of size appears to be the only one of value in a generic separation. In the present instance, however, the fossil jaws may belong to immature individuals of *Peromyscus.* Further material may show that these jaws belong to harvest mice, but for the present they are tentatively referred to *Peromyscus.*

Among the numerous isolated upper incisors from the deposit none was found which showed the grooved character or possessed a size and shape like that of *Reithrodontomys.*

Neotoma species

The material referred to the wood-rat *Neotoma* consists of one right lower jaw with $M\overline{1}$ and $M\overline{2}$, and several isolated teeth. On the basis of the small amount of material available, an attempt to make more than a generic determination does not appear to be justifiable. Two species of *Neotoma* are found living in the region of Carpinteria today, namely *Neotoma intermedia* of the subgenus *Neotoma* and *Neotoma fuscipes* of the subgenus *Homodontomys.* On the basis of size alone the fossil jaw is closer to *N. fuscipes.* Although differences in tooth pattern separate the three subgenera of *Neotoma* these characters are variable to the extent that a determination of fossil material based exclusively on tooth pattern may be subject to considerable uncertainty.

It is interesting to note that *N. fuscipes* builds houses of sticks some distance above the ground. This habit lends support to the belief that a forest environment prevailed during the period of existence of the Carpinteria Pleistocene fauna.

Microtus californicus (Peale)

The fossil material representing the California meadow-mouse *Microtus californicus* consists of numerous lower jaws, parts of two palates, and some isolated teeth. Evidence for the specific determination is presented by the shape of the incisive foramina and the occlusal pattern of the teeth. The former character can be determined even in fragmentary specimens. On the basis of the occlusal pattern of the teeth, the fossil forms resemble most closely the subspecies *M. c. californicus.*

The latter subspecies does not now inhabit the region of Carpinteria, and its presence in the Pleistocene would substantiate the view that a forest essentially similar to the Monterey forest of today was present in the vicinity of the asphalt deposits during the period of existence of the Pleistocene fauna. Possibly certain elements in the mammalian assemblage may have enjoyed a more extended range south of Monterey than is the case at the present time.

The Carpinteria asphalt species has one peculiar character that none of the Recent subspecies possesses. The first internal re-entrant angle of $M\underline{1}$ is wider than in the living species. This character of width is apparently not due to wear. The character does not warrant subspecific separation, for only two specimens of the first upper molar are available in the collection, a number certainly insufficient to demonstrate that the widely re-entrant angle is constant.

LAGOMORPHA

Lepus near californicus Gray

A jack-rabbit is represented by a single left ramus, apparently of an old individual. The tooth-row is complete with the exception of $M\overline{3}$. The specimen is evidently referable to the genus *Lepus*, as indicated by the large size and by the presence of a long diastema. $P\overline{3}$ has the shape and pattern seen in the existing species.

No difference of structure can be observed between the fossil specimen and *L. californicus*. The diastema seems long for the size of the individual, but the length is an extremely variable character and apparently has been duplicated in some of the Recent specimens of *L. californicus*.

The specimen is referred to *L. californicus* which it resembles in size. Jaws of *L. washingtonii klamathensis* are smaller and those of *L. campestris sierræ* are much larger than the Carpinteria specimen.

Sylvilagus bachmani (Waterhouse)

Remains of *Sylvilagus* from Carpinteria are very fragmentary. The collection comprises several lower jaws, portions of the maxillæ and isolated teeth. In size and length of diastema between $\overline{I}$ and $P\overline{3}$, these specimens are distinctly more like *Sylvilagus* than like *Lepus*.

Two of the species of *Sylvilagus*, *S. bachmani* and *S. audubonii*, are distinguished by their size. The former type is smaller than the latter and is further characterized by the straight anterior wall of the posterior re-entrant angle of $P\overline{3}$ and by the less complex folds in the re-entrant angles of $M\underline{1}$ and $M\underline{2}$. A large number of specimens from the Carpinteria Pleistocene possess the characters peculiar to *S. bachmani*.

The collection contains several young specimens and the separation of the two species is made with difficulty. In *S. bachmani* the third lower premolar lacks the plication seen in the posterior re-entrant angle characteristic of *S. audubonii*. The wall of the re-entrant angle in the Carpinteria species is in some cases slightly wavy. A Recent specimen of *S. audubonii* shows a $P\overline{3}$ having this character, although the Recent tooth is more of the plicated type. In this regard it may be indicated that the statement by Dice[1] that in *S. bachmani* the enamel is straight or in rare instances simply crenulated can not be verified. Recent specimens of *S. bachmani* have been found in which definite plications exist.

The first and second upper molars of the fossil material correspond in pattern to those of the Recent *S. bachmani*. One specimen from the asphalt having a size larger than the average may represent *S. audubonii*. Here again the statement by Dice[2] that, "The enamel of the anterior edge of the re-entrant angles of the first and second upper molars seems never to be more than slightly wavy in the *S. bachmani* group, and is usually a nearly straight line," is not supported by all specimens. Several specimens of the Recent *S. bachmani* are available in which the folding on these teeth can hardly be regarded as only slightly wavy.

In size the fossil specimens are all small and fall readily within the species *S. bachmani*. The presence of *S. audubonii* is not certainly indicated. However, a right maxillary with $P\underline{3}$, $P\underline{4}$, $M\underline{1}$ and $M\underline{2}$ is characterized by large size and by very well-developed plications on the re-entrant angle of

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[1] L. R. Dice, Carnegie Inst. Wash. Pub. No. 349, Art. VII, 128, 1925.

[2] L. R. Dice, *ibid.*, 129, 1925.

M$\underline{2}$. In this specimen the enamel forming the re-entrant angle of M$\underline{2}$ is more complicated than that forming the angle of M$\underline{1}$.

The morphological characters possessed by the *Sylvilagus* specimens from the Carpinteria deposit, in the light of structural features of the dentition in existing species of this genus, indicate definitely that the former types are to be referred to *Sylvilagus bachmani.* The presence of *S. audubonii* can not be definitely shown, but the sharp distinctions in enamel pattern between this species and *S. bachmani* are not maintained, as shown by the comparisons made in the present study.

ARTIODACTYLA

Camelops? cf. hesternus (Leidy)

A single lumbar vertebra, No. 32.6, Santa Barbara Mus. Pale. Coll., of a large ungulate resembles in size the comparable vertebræ in *Camelops* and *Bison.* The specimen differs more from *Bison antiquus* than from *Camelops hesternus* in this character. No. 32.6 likewise resembles the latter and differs from the former in depth of centrum and in absence of a ventral keel. Unfortunately the specimen lacks for the most part the neural spine and the transverse processes are likewise largely broken away. The articulating surface of the anterior zygapophysis is deeply cupped.

Odocoileus species

A maxillary fragment with Dp$\underline{3}$, Dp$\underline{4}$, M$\underline{1}$ and M$\underline{2}$, a ramus with Dp$\overline{4}$, two isolated teeth, Dp$\underline{4}$? and M$\overline{1}$?, and fragmentary remains of limb elements have been referred to this genus.

The maxillary fragment, No. 32.5 Santa Barbara Mus. Pale. Coll., is comparable, in so far as can be determined, to specimens of *O. hemionus.* Unfortunately a maxillary of *O. hemionus* in a similar stage of development is not available for comparison. A specimen of *O. columbianus scaphiotus* (Dickey Coll. No. 14,389) presents a stage of tooth wear comparable to that in No. 32.5. Comparisons show the Carpinteria specimen to be larger and to have less development of the internal basal cuspule in M$\underline{1}$ and M$\underline{2}$. The metacone rib in No. 32.5 is only faintly marked if at all developed in the permanent molars.

Much of the limb material represents the remains of young individuals and is too poorly preserved to be accurately determined. However, a distal end of a humerus, a proximal end of an ulna, a distal epiphysis of a femur, two calcanea, and a navicular-cuboid possess enough character to assure reference to the genus *Odocoileus.* It should be stated that because of the fragmentary and immature state of much of the material, the reference of at least some of the specimens to *Antilocapra* can not be wholly eliminated.

Bison? species

A large navicular-cuboid, No. 1294, Calif. Inst. Tech. Coll. Vert. Pale., of a young individual may represent a bison. This specimen is too large to permit reference to the deer or antelope, and differs rather distinctly in several characters from the corresponding element of the genus *Cervus.*

In No. 1294 the posterior part of the calcanear facet is like that in *Bison antiquus* in not ascending sharply to a distinct process as is the case in *Cervus.* No. 1294 also agrees with *Bison antiquus* in having the metatarsal facet nearly horizontal. In *Cervus* the facet is inclined from the horizontal, the anterior portion being depressed. Furthermore, No. 1294 corresponds to the navicular-cuboid of *Bison* in lacking the depth seen in that element in *Cervus*. Although the navicular-cuboid of *Cervus* is distinctly smaller than in *Bison*, the actual depth is not much less.

On the other hand, No. 1294 agrees more closely in size with the corresponding element in *Cervus* than it does with one of the smaller specimens of the navicular-cuboid of *Bison antiquus* from Rancho La Brea available in the large collections of the Los Angeles Museum. No. 1294 differs from both *Bison* and *Cervus* in the extreme shallowness of the transverse depression between the external cuneiform facet and the transverse facet for articulation with the metatarsal element. However, this character may be due to the immature character of the specimen.

PERISSODACTYLA

Equus near occidentalis Leidy

The horse material from the Carpinteria asphalt is limited to limb elements. A metatarsal, proximal fragment of femur, calcaneum, astragalus, first phalanx, ungual phalanx, and fragments of a sacrum and pelvis represent the adult material at hand. The limb elements are comparable in size to specimens of *Equus occidentalis* and probably represent that species. Specimens of *Equus occidentalis* from Rancho La Brea and McKittrick show considerable variation in size and a larger collection is necessary to determine the Carpinteria material accurately. In character of size the Carpinteria specimens make apparently a closer approach to *E. occidentalis* than to *E. pacificus*.

VII

THE COCONINO SANDSTONE—ITS HISTORY AND ORIGIN

By Edwin D. McKee
Park Naturalist, Grand Canyon, Arizona

With fourteen plates and five text-figures

[Issued November 1933]

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THE COCONINO SANDSTONE—ITS HISTORY AND ORIGIN[1]

INTRODUCTION

Many early geologists in describing their explorations of the northern Arizona plateau have mentioned several formations now known to be of Permian age. Powell, Dutton, Walcott, and others showed these in published sections, and the geologists of the Wheeler and Powell Surveys referred to them as the Aubrey Group. The white cross-bedded sandstone in this group was known as the "Upper Aubrey" sandstone, but Darton[2] later changed this to Coconino in order to simplify the nomenclature. In more recent years the Coconino has been studied in some detail by Noble, and it was included in the stratigraphic studies of Reeside, Baker, Gregory and others. Gilmore has studied and partially described the fossil tracks and trails of animals which are found in this formation.

The Coconino sandstone is a distinctive stratigraphic unit which underlies much of the plateau of northern Arizona and which is characterized by its prominent cross-bedding, its uniformly small sand grains, and its general cliff-forming character. In the Grand Canyon and in most other localities where exposed, it is white or buff in color, but in the Marble Canyon it appears brownish, and in places near Flagstaff its color is bright red. This formation is a prominent feature of the Mogollon and Grand Wash cliffs of Arizona which are its southern and western limits, respectively. Eastward it definitely extends as far as Holbrook, while to the northeast it is found at Kin-la-chee Canyon near Ganado beyond which it grades laterally into the upper part of the De Chelly sandstone as seen in Nazlini Canyon and at Fort Defiance. To the north it thins to extinction near the Utah border, disappearing about ten miles south of Fredonia and a few miles southwest of the Paria River.

The problem of the Coconino sandstone has many aspects. Despite the numerous references to it in geological literature, many of its features have remained questionable. The manner of its deposition—whether by wind or by water—has long been in dispute. The source of the sand grains, the way in which they were transported, the age of the formation, and its exact relationship to others of the Permian period have been subjects of much debate.

In the study of the Coconino formation, both field and laboratory investigations have been carried on. Almost every locality where it is well exposed was visited, and at each the thickness was measured and the strata were carefully examined for any features which might aid in the interpretation of their genesis. Petrographic examinations, sieve analyses, and other studies were carried on in the laboratory to obtain information concerning the composition and texture of the formation. These data were of value in explaining the source of the sediments and the manner of transportation.

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[1] Published with the permission of the Director of the National Park Service.

[2] N. H. Darton, *A reconnaissance of parts of northwestern New Mexico and northern Arizona,* U. S. Geol. Survey Bull. 435, p. 27, 1910.

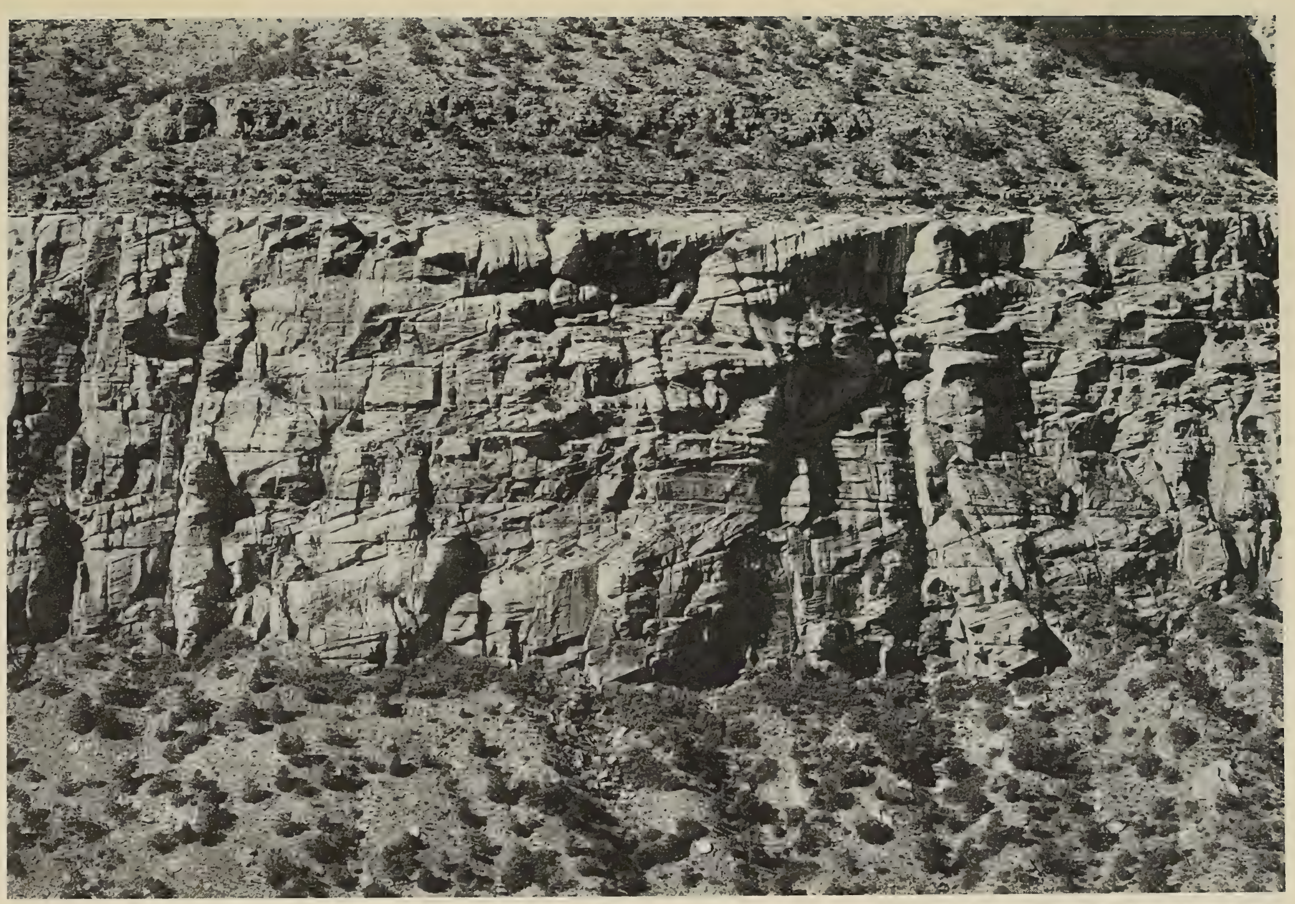
The impossibility of completely solving the problems of the Coconino sandstone without also studying in detail the other Permian formations is realized. Nevertheless, it is believed that some contribution to our understanding of the nature and origin of this formation has been made. The present paper deals primarily with the type Coconino—the white or light buff, cross-bedded sandstone exposed in the walls of the Grand Canyon and its tributary gorges, along the southern border of the Arizona plateau and in a few other localities. Although it would be desirable to include all of the possible extensions of the Coconino formation in this paper, it is impossible to do so because of difficulty of access to the localities at which the Cedar Mesa, Utah "Coconino," and other similar sandstones are exposed has prevented the writer from visiting them. On the other hand, the typical Coconino, as generally accepted, forms a well-defined unit, offering no doubt as to its continuity and having definite natural limits on at least three sides. It should be remembered, furthermore, that observations and conclusions concerning the origin, transportation and deposition of the sand of which the Coconino is made, apply to it only in the region studied, whereas in adjoining areas, even though the sandstone may be continuous with the typical Coconino, any one or all of these conditions may have been different.

ACKNOWLEDGMENTS

The author's acknowledgments with thanks are most cordially extended to the Carnegie Institution of Washington for making possible the publication of this paper, and especially to its president, Dr. John C. Merriam, for first pointing out the possibilities of this work and for encouraging its completion. To Dr. H. Ries and Professor C. M. Nevin of the Cornell University Geology Department for their kind assistance and for the use of the University laboratories, and to Professor A. A. Stoyanow and his associates at the University of Arizona for similar assistance, the writer is also greatly indebted. Appreciative thanks are likewise extended to Messrs. F. E. Matthes and Herbert Gregory of the U. S. Geological Survey, and to Dr. N. E. A. Hinds of the University of California for much constructive criticism and other assistance.

STRATIGRAPHY

The complicated stratigraphic relations between the Coconino sandstone and associated formations of Permian age in northern Arizona and adjoining parts of Utah, Colorado and New Mexico have been



Photograph by G. Grant, Courtesy Nat'l Park Service.

Cliff of typical Coconino sandstone, Hermit Basin, Grand Canyon, Arizona.

described recently by Baker and Reeside.[1] These writers point out that the Permian formations of which the principal kinds of sequence are represented at Grand Canyon, Monument Valley, and southwestern Colorado, probably interfinger with each other over a large area, and that the three principal types of deposits represented in them, namely, the red beds, the limestones and the light-colored cross-bedded sandstones, were formed by sediments coming from several different directions during the same general period. The Coconino, as described from the type locality at Grand Canyon, is considered in that paper to be continuous with the white cross-bedded sandstone of Circle Cliffs and San Rafael Swell, Utah, and with the Cedar Mesa and De Chelly sandstones to the east and northeast. Unfortunately the overlying Mesozoic rocks in southeastern Utah and in the Painted Desert country make it impossible to trace such a relationship, so the validity of the correlation remains to be established.

Types of Permian Sequence—Baker and Reeside

Grand Canyon	Monument Valley	Southwest Colorado
Kaibab Limestone	Cutler Formation	Cutler Formation
Coconino Sandstone	Hoskinini Tongue	(Undivided red beds)
(Light-colored, cross-bedded)	(Red beds)	Rico Formation
Hermit Shale	De Chelly Sandstone	(Red beds, limestone)
(Red beds)	(Light-colored, cross-bedded)	
Supai Formation	Organ Rock Tongue	
(Red beds)	(Red beds)	
	Cedar Mesa Sandstone	
	(Light-colored, cross-bedded)	
	Halgaito Tongue	
	(Red beds)	
	Rico Formation	
	(Red beds and limestone)	

The typical Coconino is a uniformly fine-grained, nearly pure quartz sandstone with siliceous cement. It has a massive appearance and is cross-bedded on a huge scale. This sandstone is known to extend continuously from Seligman, Pine, and Holbrook on the south, to upper Kanab Canyon and Lees Ferry on the north, and has been observed to become progressively thinner (fig. 1) from its southern limits toward the area bordering the Utah-Arizona boundary, where it apparently disappears. As shown by Gregory and Noble,[2] the Coconino sandstone disappears in upper Kanab Canyon, is 25 feet thick at Ryan on the west side of the Kaibab Plateau, and is lacking in Kaibab Gulch (about 30 miles northwest of the upper Marble Gorge) where the Kaibab limestone rests on Hermit shale. The first two of these observations have been carefully checked by the writer. Further evidence of the northward thinning of the Coconino sandstone is found in the walls of Marble Canyon near Lees Ferry, where the writer found it to have a thickness of only 57 feet. (This measurement which is at variance with that of Moore[1] is further discussed under "Upper Contact" on page 89.)

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[1] A. A. Baker and John B. Reeside jr., *Correlation of the Permian of Southern Utah, Northern Arizona, Northwest New Mexico, and Southwest Colorado*, Amer. Assoc. Petroleum Geologists Bull., vol. 13, No. 11, Nov. 1929.

[2] H. E. Gregory and L. F. Noble, *Notes on a geological traverse from Mojave, California, to the mouth of the San Juan*, Amer. Jour. Sci., 5th ser., vol. 5, pp. 229 to 238, 1923.

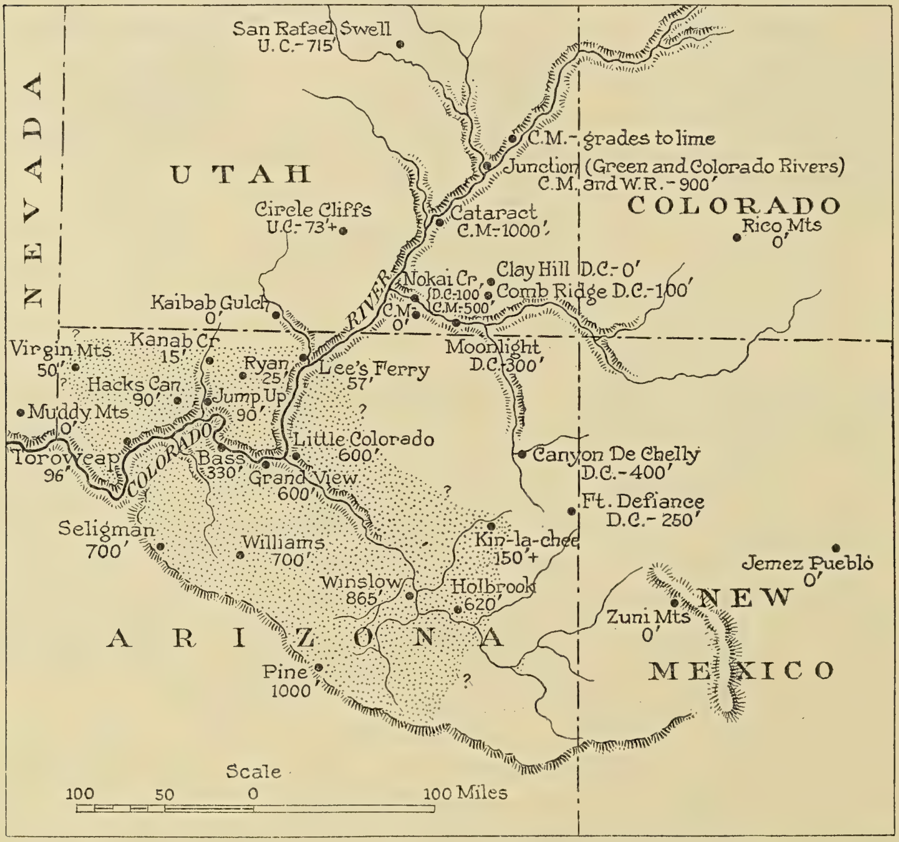
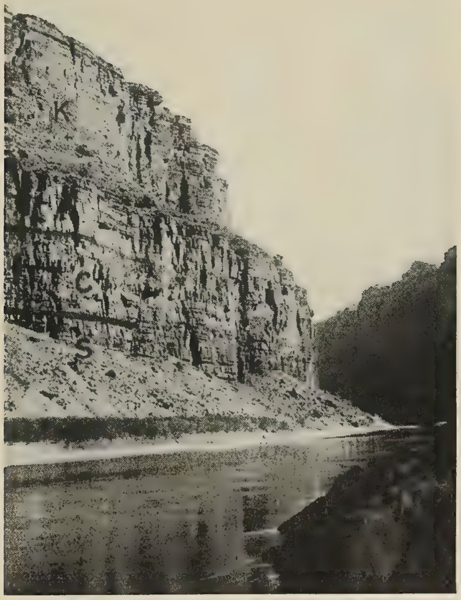


FIG. 1. Map showing location and the thickness of Permian cross-bedded sandstones, Arizona. Stippling indicates area occupied by typical Coconino sandstone; D. C., De Chelly sandstone; C. M., Cedar Mesa sandstone; U. C., Utah Coconino sandstone; W. R., White Rim.

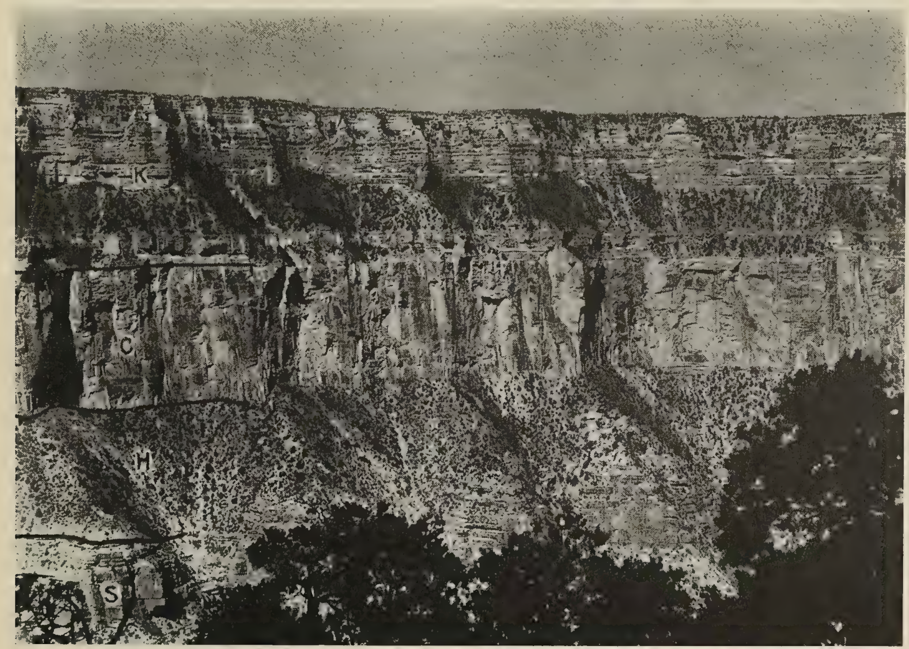
At Circle Cliffs and San Rafael Swell, Utah, "a light creamy-white, more or less cross-bedded sandstone that underlies the lowest observed limestone" has been referred by Gregory and Moore[2] and by several others to the Coconino sandstone. Unfortunately the writer has not had opportunity to visit these localities so must rely on the descriptions of others in making a comparison. Apparently the stratigraphic

[1] H. E. Gregory and R. C. Moore, *Kaiparowits Region, Utah-Arizona*, U. S. Geol. Surv. Prof. Paper 164, p. 44, 1931.

[2] *Ibid.*, pp. 40, 45.



a. Permian formations in Marble Canyon, 7½ miles southwest of Lees Ferry, Arizona. (Coconino 57 feet thick).
K, Kaibab limestone; C, Coconino sandstone; S, Supai formation.



Photograph by G. Grant, Courtesy Nat'l Park Service.

b. Permian formations in Grand Canyon, Arizona. (Coconino about 350 feet thick).
K, Kaibab limestone; C, Coconino sandstone; H, Hermit shale; S, Supai formation.

position of this Utah "Coconino" is the only justification for applying that name to it. Gregory and Moore state—

> "It differs in no essential respect from the sandstone in the lower part of the Kaibab and is undoubtedly conformable with the bed above; indeed the definition of the beds is somewhat arbitrary."

A comparison of this sandstone and the typical Coconino sandstone shows that they are different in many respects. To quote Gregory and Moore further—

> "The occurrence of marine shells in the sandstone of Circle Cliffs, and its calcareous character contrast with the vertebrate tracks and siliceous character of the typical Coconino." And again, "A few of the rounded grains consist of limestone. The cross-bedding is neither so prominent nor so uniform as that in the Coconino in Grand Canyon; the individual cross-bedded lenses are much thinner, and the platy weathering of the cross-laminæ is much less striking. In general, the rock appears less resistant to weathering than the type Coconino and forms rounded 'bouldery' surfaces between irregularly disposed joint planes."

Furthermore, as pointed out by these writers and as already indicated in this paper, the thinning of the typical Coconino sandstone to the vanishing point near the Arizona-Utah border, makes rather apparent the conclusion that the sandstone termed "Coconino" in southeastern Utah is perhaps not an equivalent of and certainly is not a continuation of the Coconino of the Grand Canyon, but should more properly be termed a sandy phase of the overlying Kaibab limestone.

The Cedar Mesa sandstone of the Monument Valley section which has been suggested by Reeside and Baker[1] as a continuation of the Coconino sandstone is described by them as thinning southward until, not far below the San Juan river, it disappears (fig. 1). Its northern limit, according to the same writers, is just above the junction of the Green and Colorado Rivers, where it changes abruptly (with a thickness of about 1000 feet) into a material of an entirely different nature, "red or purplish to salmon, coarse-grained, arkosic sandstones with a small amount of shale." Furthermore, it has been suggested by Baker and Reeside that the sandstone of the Circle Cliffs region to the west is probably continuous with the Cedar Mesa sandstone, but since for a distance of nearly 70 miles between Circle Cliffs and Moonlight Creek, Utah, neither of these formations is exposed, it has been impossible to verify this idea. For a similar reason their suggestion that the Cedar Mesa sandstone is continuous with the Coconino has little support, and it appears to the writer improbable since the directions of thinning and thickening of these formations are opposite. Further evidence of the invalidity of this correlation is presented by Gregory[2] who states that the Cedar Mesa sandstone has calcareous cement, calcareous mud shales, and true limestones in contrast to the notably small lime content of the Coconino, and that it has cross-bedding which "seems neither so prominent nor so uniform as that in the Coconino."

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[1] A. A. Baker and John B. Reeside jr., *Correlation of the Permian of Southern Utah, Northern Arizona, Northwest New Mexico, and Southwest Colorado*, Amer. Assoc. Petroleum Geologists Bull., vol. 13, No. 11, Nov. 1929, p. 1420.

[2] H. E. Gregory, *The San Juan Country*, MS., pp. 37, 38.

Also, fragments of shells have been found in this sandstone—a feature as yet unknown and scarcely to be expected in the type Coconino.

The De Chelly sandstone of northeastern Arizona and southeastern Utah also has been considered by Baker and Reeside, and likewise by Darton,[1] as a probable continuation of the Coconino sandstone. As defined by Baker and Reeside, the De Chelly extends from Fort Defiance on the south, where it is 250 feet thick, to the region of the San Juan on the north, near where it becomes very thin and finally disappears. In the latter area they found it to be above the Cedar Mesa sandstone, and to be separated from it by red beds.

That the De Chelly sandstone is not an extension of the true Coconino, however, is considered by the writer[2] to be definitely established since these formations differ in type of cross-bedding, in mineral content, in kind of cement, and in variety of grain size. The nearest occurrence of sandstone which appears to be typical Coconino in every respect and which contains footprints of Coconino species of vertebrate animals is found at Kin-la-chee Canyon, 30 miles south of Canyon de Chelly. This sandstone apparently grades laterally into the upper part of the De Chelly sandstone both at Nazlini canyon and at Fort Defiance At Nazlini, furthermore, footprints similar to those in the Coconino occur in the mixed type of sandstone. In brief, the writer considers the upper De Chelly sandstone and the Coconino sandstone to have been formed contemporaneously, but under different conditions of deposition and from materials derived from different sources.

Still another formation of cross-bedded white sandstone, known as the White Rim[3] is exposed in the Colorado Plateau area. It appears as a wedge of small extent at the top of the red beds above the Cedar Mesa sandstone in the extreme northern part of this region. Baker and Reeside were unable to trace any relationship between it and the other cross-bedded white sandstones of the plateau, but Gregory[4] considers it an extension of the De Chelly sandstone.

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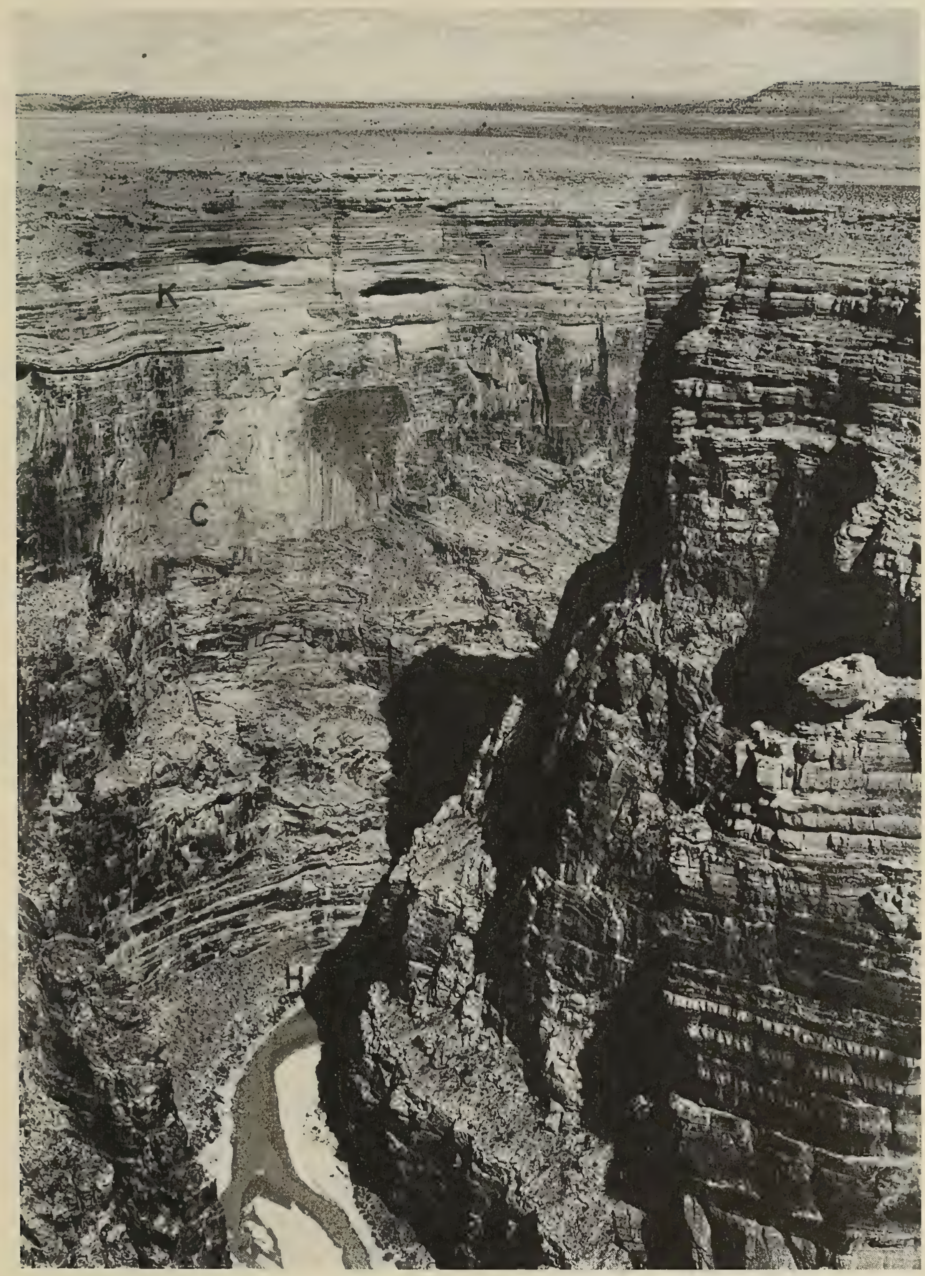
[1] N. H. Darton, *Resumé of Arizona Geology*, Univ. Ariz. Bull. No. 119, 1925.

[2] E. D. McKee, *Report on investigation of the light-colored, cross-bedded sandstones of Canyon de Chelly, Arizona.* Unpublished, Nat. Park Service, 1932.

[3] A. A. Baker and John B. Reeside in *Correlation of the Permian of Southern Utah, Northern Arizona, Northwest New Mexico and Southwest Colorado*, Amer. Assoc. Petroleum Geologists Bull., vol. 13, No. 11, Nov. 1929.

[4] H. E. Gregory, personal communication, 1932.



Photograph by G. Grant, Courtesy Nat'l Park Service.

Permian formations in canyon of the Little Colorado, Arizona. (Coconino about 600 feet thick.) K, Kaibab limestone; C, Coconino sandstone; H, Hermit shale.

The probable relations of the Permian strata to one another in the Arizona-Utah plateau region have been summed up by Baker and Reeside[1] as follows:

> "Apparently the Permian began with the widespread deposition of red beds derived from the east, except in the extreme west part of the area where light-colored sands were laid down. In the east a few marine limestones (Rico) interrupted the sequence of red materials, representing incursions of a sea from the east. These first red deposits were followed by light-colored sands coming from the northwest (Coconino, etc.) which interfingered with the red materials that still continued to come in from the east. Then marine waters gradually advanced from the west across the western half of the area, depositing chiefly limestones (Kaibab). East of the sea the light-colored sandstones were the chief deposits in a wide zone, and still farther east the red materials prevailed. Finally, the sea withdrew with seeming abruptness and the whole area was exposed to the period of erosion represented by the unconformity at the base of the Triassic."

As already stated, while the validity of most of these correlations remains to be established, they form a basis upon which to begin a study of the complicated relationships between the various Permian formations. The results of the detailed studies of one unit which are presented in this paper help to establish some parts of the theory and also to show the errors in others. Evidence that the Coconino is not a continuation of the other light-colored, cross-bedded sandstones or of the conditions which they represent has been given, while evidence that the source of the Coconino was to the south, also contrary to the theory of Baker and Reeside, will be found in a later section. In most other details, however, the writer is in agreement with their theory.

CONTACTS OF TYPICAL COCONINO SANDSTONE

Special attention has been given by the writer to both the lower and the upper contacts of the Coconino sandstone in the areas visited. Certain of the features noted seem to have an important bearing on the Permian stratigraphic problems and for that reason are described here.

BASAL CONTACT

The Hermit shale which underlies the Coconino sandstone throughout the Grand Canyon area is composed of red silts, shales and fine sands of probable fluvatile origin.[2] In western Grand Canyon this formation is over 500 feet thick and forms the floor of the "Esplanade" bench, but to the east it thins steadily until near the junction of the Colorado and Little Colorado Rivers it measures only about 100 feet. Numerous ferns and other plants, many of which have been described by White, as well as some insect wings and the tracks of vertebrate animals have been found in it.

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[1] A. A. Baker and John B. Reeside jr., *Correlation of the Permian of Southern Utah, Northern Arizona, Northwest New Mexico, and Southwest Colorado,* Amer. Assoc. Petroleum Geologists Bull., vol. 13, No. 11, Nov. 1929, p. 1413.

[2] David White, *Flora of the Hermit Shale, Grand Canyon, Arizona,* Carnegie Inst. Wash. Pub. No. 405, p. 17, Dec. 1929.

The Coconino-Hermit contact is well exposed in many places (fig. 2) in the Grand Canyon where the white color of the former makes a strong contrast with the red of the latter. Near the Hermit, Bright Angel, Kaibab, Yaki, and Grand View Trails the contact is sharp (Plate 4; *a-d*). At these places there is an abrupt change from the red shales (in some areas sandstones) of the Hermit to the white sandstone of the Coconino. This change, which apparently is due to disconformity, forms a remarkably even contact line from which large cracks due to sun shrinkage and filled by the white sand from above, extend down into the Hermit in many places (Plate 4; *b*, *d*).

Near the Bass Trail a layer of calcareous clay 2 feet in thickness, and varying in color from gray to red, comes between the soft Hermit mud and the slightly sloping laminæ of the cross-bedded, basal Coconino sandstone. A somewhat similar limy clay was noted in Hance Canyon where it extends downward in seams, one of which was measured to be 8 inches wide and 20 feet deep. Beside these and running into them are the much smaller and narrower shrinkage cracks which are filled with sand from above. The significance of the calcareous clay is not yet clear to the writer.

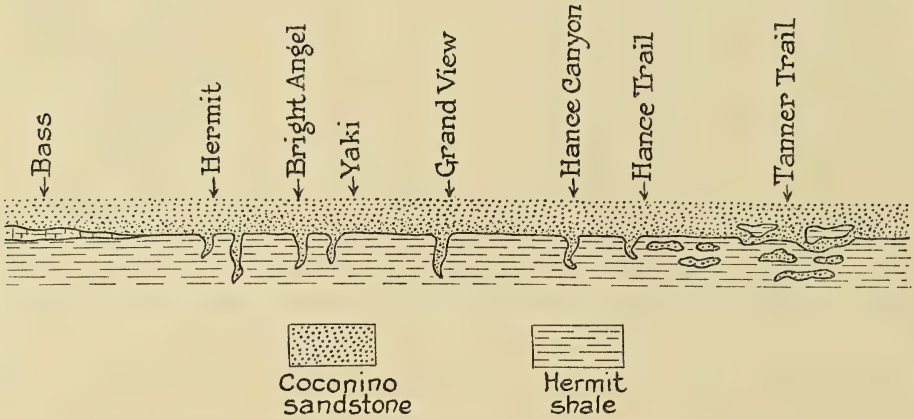
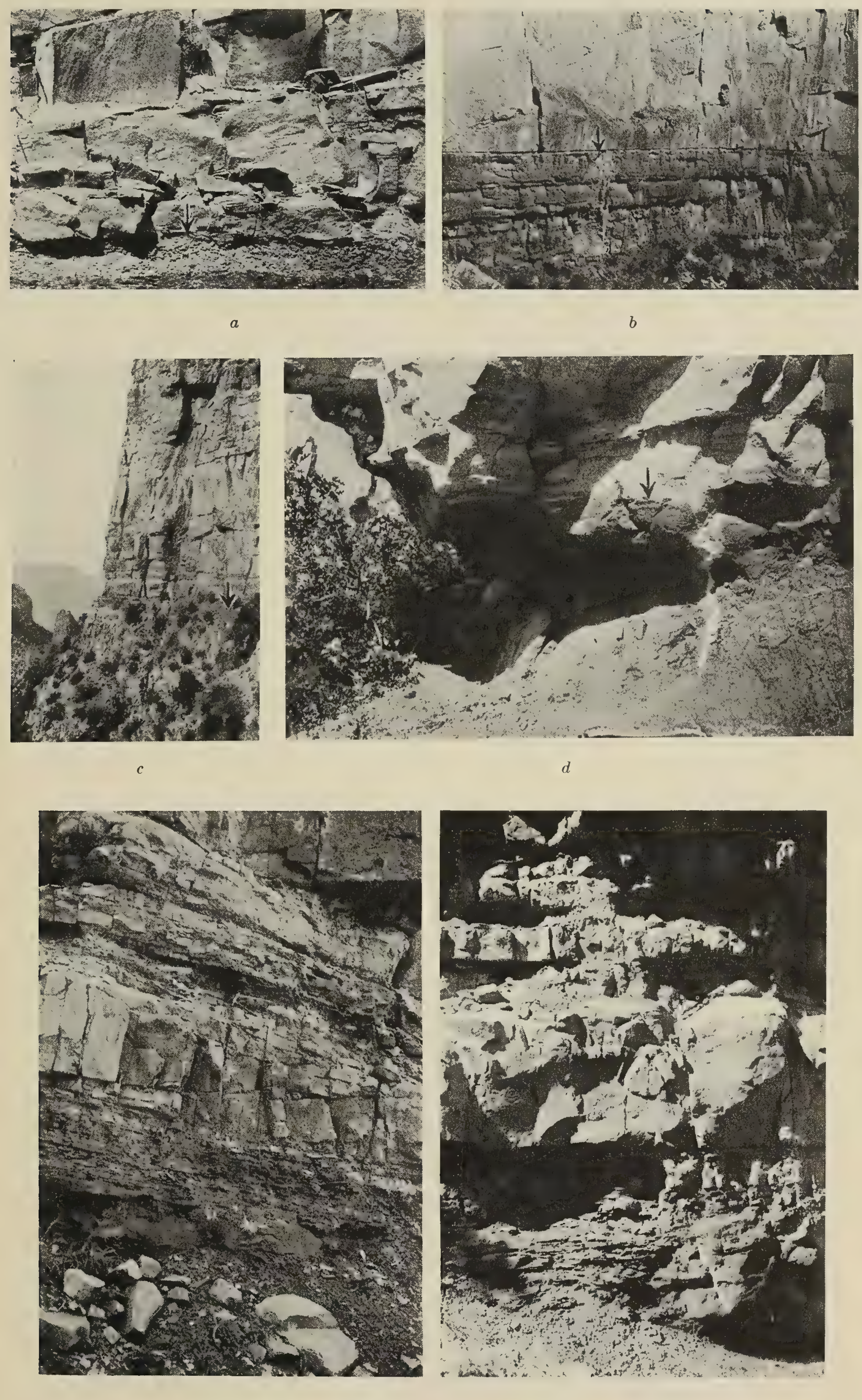


Fig. 2—Diagram of relationship of Coconino sandstone to Hermit shale.

Probably the most important feature noted in connection with the Hermit-Coconino contact is the conformity in the vicinity of Tanner Trail in extreme eastern Grand Canyon. Here the Hermit shale grades vertically into the Coconino sandstone. An area of transition exists with thin beds of crumbly red shale of the Hermit type, separated by layers of resistant white sandstone of the Coconino type (Plate 4; *e*, *f*). These alternating layers of red shale and white sandstone appear in a vertical section for 15 or 20 feet, thus proving conformability at that locality.



a b c d e f

a. Coconino-Hermit contact, Yaki Trail, Grand Canyon.
b. Coconino-Hermit contact, Bright Angel Trail, Grand Canyon.
c. Coconino-Hermit contact, Hance Canyon, Grand Canyon.
d. Coconino-Hermit contact, Kaibab Trail, Grand Canyon.
e. Grading contact of Coconino-Hermit, Tanner Trail, Grand Canyon.
f. Grading contact of Coconino-Hermit, Tanner Trail, Grand Canyon.

Near the Hance Trail in Red Canyon is found a definite contact line with sand-filled shrinkage cracks extending down into the Hermit shale as in most other localities. At some places near the top of the Hermit, however, are pockets of the Coconino sandstone. These appear to be due to a gradational change in sedimentation, similar to but less extensive than that represented on the Tanner Trail farther east.

The conformity between the Hermit shale and Coconino sandstone in eastern Grand Canyon seems to be good evidence that the hiatus between the two in other areas is not great. Moreover, it helps to substantiate the theory of Baker and Reeside, which calls for a change in source and type of sediments, as the explanation for the change in formations at Grand Canyon.

Contacts of Hermit Shale and Coconino Sandstone in Grand Canyon

Locality	Nature of Hermit	Mud cracks in Hermit	Type of Contact	Special Features
Bass Trail	Crumbly mud	Not noted	Sharp	2 in. layer grey lime between sandstone and shale
Hermit Trail	Crumbly mud	Not noted	Sharp	
Bright Angel Trail	Sandy, resistant	Prominent	Sharp	
Yaki Trail	Crumbly mud	Not noted	Sharp	
Grand View Trail	Sandy, resistant	Present	Sharp	
Hance Canyon	Sandy, resistant	Present	Sharp	"Veins" of lime in upper part Hermit
Hance Trail	Sandy, resistant	Present	Sharp?	Pockets of Coconino below contact line
Tanner Trail	Sandy, resistant	Not noted	Grading	No unconformity

In most of the Coconino exposures outside of the Grand Canyon which the writer has visited, the basal contact was not exposed. To the south it was seen only in Oak Creek Canyon where the white Coconino sandstone grades downward into red beds which probably represent either the Hermit or the Supai formation. These red beds differ materially from those of the Grand Canyon, since they contain much sandstone which is cross-bedded like the Coconino but composed of considerably finer sand grains. Horizontally bedded, dull red sandstones and shales, similar to those found in parts of the type Hermit shale and Supai sandstone occur between layers of these red cross-bedded sandstones, increasing in amount toward the bottom of the formation. The base of the Coconino and the top of the underlying formation in this area have not been determined with certainty by the writer, but the area of gradation occurs at about the upper limit of the highest horizontal red beds which in most exposures is at the boundary between the white and the red sandstones.

To the north of Grand Canyon a distinct line of contact was noted between the Coconino sandstone and the Hermit shale at Big Springs in the Kaibab Forest. At Lees Ferry a disconformity exists between the Coconino and what is believed to be the Supai formation.[1]

UPPER CONTACT

Throughout the Grand Canyon region, except in the east near Holbrook, the Coconino sandstone is overlain by the Kaibab formation. Everywhere there appears to be a distinct unconformity between these formations, with the cross-bedded upper levels of the Coconino beveled to a flat surface. The Kaibab is mainly a gray, sandy, fossiliferous limestone of shallow-water marine origin. Some horizons are extremely cherty, and many of them are massive and form conspicuous cliffs. In contrast to these, however, are the crumbly and shaly sandstone layers which occur in the lower and in the middle parts throughout the Grand Canyon and several other areas.

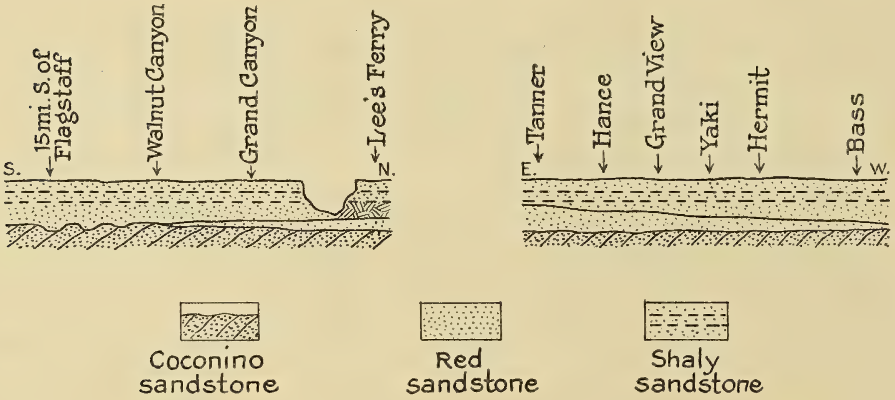


Fig. 3—Diagram of relationship of Coconino sandstone to Kaibab limestone.

To the east of Holbrook, Arizona, the typical Coconino sandstone is unconformably overlain by the Moencopi formation (Plate 7) of Triassic age and in Kin-la-chee Canyon near Ganado by the Shinarump conglomerate, also of Triassic age, which fills many erosion channels in the top of the Coconino. The absence of Kaibab limestone in these areas is explained by the fact that the formation thins from west to east and finally disappears in the vicinity of Holbrook.

South of Flagstaff and in Walnut Canyon, the Coconino sandstone is covered by a gray sandy limestone member of the Kaibab formation (Plate 6; *b*). In Walnut Canyon the contact between these formations is horizontal, but farther south and west the limestone appears to fill small erosion channels in the top of the Coconino.

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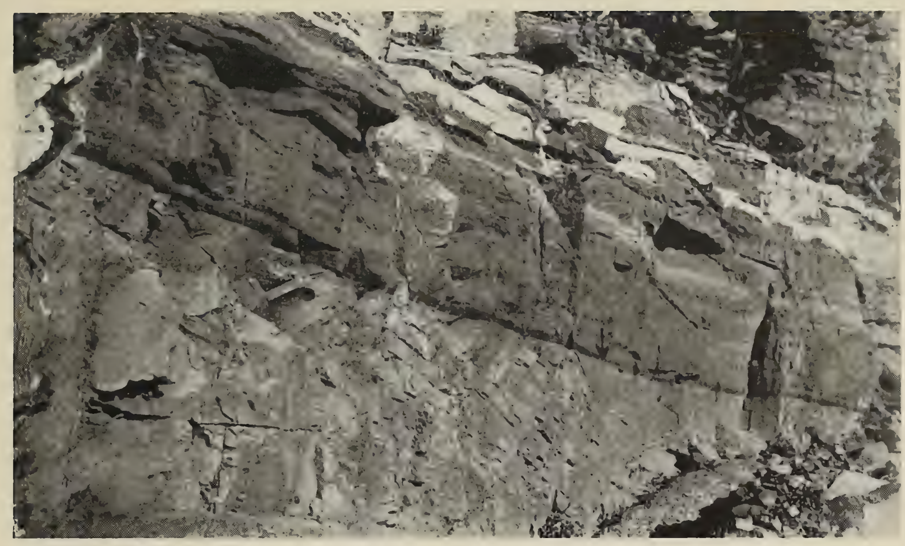
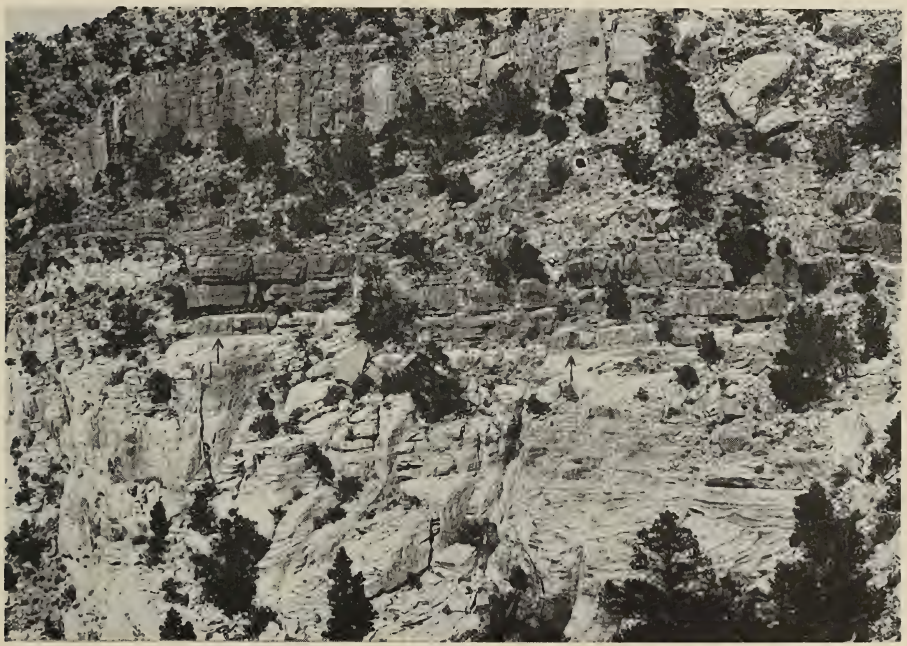
[1] The Hermit shale is thought to taper to extinction in the lower part of the Marble Canyon, judging from the direction and amount of its thinning in the Grand Canyon.



a. Kaibab-Coconino contact, Yaki Trail, Grand Canyon.



Photograph by G. Grant, Courtesy Nat'l Park Service.

b. Kaibab-Coconino contact, near Hermit Trail, Grand Canyon.

Near Seligman, throughout the Grand Canyon, and north of it, a thin bed of red sandstone forms the base of the Kaibab formation. Everywhere its lower surface makes a conspicuous horizontal contact line with the truncated sloping beds at the top of the Coconino formation (Plate 5; *a*, *b*. Plate 6; *a*). This red sandstone is composed of very fine-grained red material which is interspersed with medium-sized white quartz grains (Plate 8; *c*) which make it easily recognizable. At Badger Canyon, near Lees Ferry, the writer believes that bed 5 of Moore's section is the same red sandstone that marks the base of the Kaibab formation in Grand Canyon, and thin sections made from it seem to verify this conclusion. If this be correct, the cross-bedded and other sandstones of beds 6 and 7 correspond to the lower sandy parts of the "C" member of the Kaibab limestone of Grand Canyon, and the total thickness of the Coconino sandstone at Badger Canyon is only 57 feet.

Section of Wall of Marble Gorge opposite mouth of Badger Creek, 7½ miles below Paria River. (Measured by Raymond C. Moore.)

Coconino Sandstone:	Feet
7. Sandstone, reddish brown, generally hard but locally soft, crumbles in hand; lower 2 feet a massive layer, irregularly bedded; next 3 feet unevenly laminated horizontally; upper 10 feet irregularly bedded, rather massive; weathers in rounded surfaces, nodules at top	15
6. Sandstone, yellowish brown, hard, thin bedded, each stratum cross-bedded; weathers in platy fragments, stained black on surface	6
5. Sandstone, light red, soft, somewhat irregularly stratified; the layers cut across inclined laminæ of subjacent bed	15
4. Sandstone, light yellow, a single hard massive ledge, cross-bedded; breaks in large blocks, prominently stained with desert varnish	5
3. Sandstone, yellowish, highly cross-bedded; weathers in slabs that break oblique to the bedding; massive	18
2. Sandstone, very light yellow, sugary, prominently cross-bedded, the inclined laminæ dipping southward; siliceous cement; very massive	34
Total Coconino Sandstone	93

Contacts of Coconino sandstone and overlying formations

Locality	Nature of Kaibab	Type of contact	Special features
Kin-la-chee Canyon	None	Erosion	Shinarump conglomerate above
Near Holbrook	None	Erosion	Moencopi formation above
15 mi. s. Flagstaff	Grey limestone	Slight erosion	
Walnut Canyon	Grey limestone	Sharp	
Seligman	Red sandstone	Sharp	
Grand Canyon, all trails	Red sandstone	Sharp	Coconino cross-bedding truncated
Lees Ferry	Red sandstone	Sharp	Cross-bedding above red sandstone

The Kaibab limestone probably was formed in a shallow sea which came in from the west and northwest, as is suggested by its thinning to extinction near Holbrook and by its Pacific fauna. The red sediments at its base appear to have been worked over by shallow water, but no proof of this has been found. That the Kaibab began to be formed not long after the end of Coconino time is indicated by the absence of erosional features at the top of the Coconino and by the remarkably even contact which suggests that the yet unconsolidated uppermost Coconino beds were merely beveled and reworked with the encroachment of the Kaibab Sea. It is possible, therefore, that the basal Kaibab sands and limes were accumulating in the northwestern part of the region at the same time that the uppermost Coconino sands were being deposited to the east, an opinion to which the opposite directions of thinning in these two formations gives considerable support.

COMPOSITION AND TEXTURE

Composition and textural features of the Coconino sandstone were carefully examined with the hope that some of them would give evidence concerning the history and origin of the formation. A series of typical specimens from most of the exposures and from various horizons of the type Coconino were examined for (1) the amount of quartz present, (2) clay and lime content, (3) iron content, (4) presence of feldspar, (5) presence of heavy minerals, (6) fineness of grain, (7) uniformity of grain, and (8) degree of rounding, frosting and pitting. It would have been desirable to include specimens from the possibly related De Chelly, Cedar Mesa, and Utah "Coconino" sandstones in this work, but such specimens, unfortunately, the writer was not able to obtain.

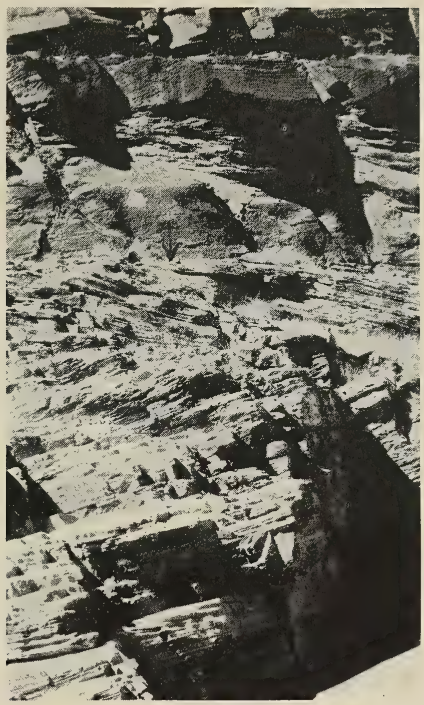
Textural features serve only as criteria of *source* and *mode of transportation* of sediments—not as indicators of modes of deposition. In the case of the Coconino, they give good evidence concerning the source, *i. e.* the direction from which the material came, but very little direct evidence regarding the agent of transportation. A discussion of the various phases of this study follows.

QUARTZ

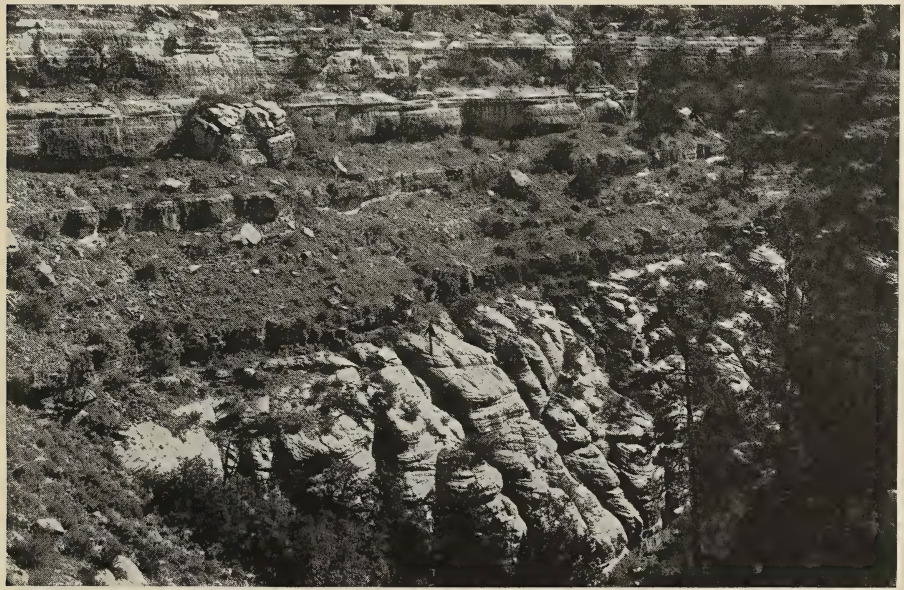
The typical Coconino of the Grand Canyon region is a uniformly fine-grained sandstone characterized by a great preponderance of quartz (Plate 8; *b*, *d*). Laboratory examination indicates that this mineral composes from 88 to 95 per cent of the formation. The remainder consists chiefly of clay and lime carbonate with iron oxides occurring locally, and a trace of both feldspar and heavy minerals scattered throughout. The cement of the sandstone is chiefly silica.

CLAY AND LIME CARBONATE CONTENT

Combined clay and carbonate content as measured in samples of sandstone from various horizons near the Bright Angel Trail, Grand



a. Kaibab-Coconino contact, Badger Canyon near junction with Marble Canyon, 7½ miles southwest of Lees Ferry, Arizona.



Photograph by G. Grant, Courtesy Nat'l Park Service.

b. Kaibab-Coconino contact, Walnut Canyon, near Flagstaff, Arizona.

Canyon, range from 5.1 to 11.1 per cent at intervals of 25 feet vertically, as shown above. These two substances were not differentiated in this work.

Near base	5.1 p. ct.	100 ft. above	9.77 p. ct.
25 ft. above	6.3 p. ct.	150 ft. above	10.70 p. ct.
50 ft. above	5.48 p. ct.	175 ft. above	11.10 p. ct.

Of 18 samples from widely separated localities and horizons which were tested with acid for lime carbonate, only 5 showed any evidence of its presence. Of these, 4 were from the upper part of the formation, thus suggesting secondary lime from the calcareous Kaibab formation above.

So far as known, neither clay nor carbonate content throws any light upon the environmental conditions of Coconino time. The information obtained has its chief value as an aid in comparing the typical Coconino sandstone with other cross-bedded, light-colored Permian sandstones of the region. The small lime content of the Coconino makes a good diagnostic feature, useful in correlation. The Utah "Coconino" and the Cedar Mesa sandstones of the regions northeast of Lees Ferry have calcareous cement, and contain calcareous mud shales and true limestones. The De Chelly sandstone has both iron and lime for cementing materials.

IRON OXIDE CONTENT

In most places where it is exposed, the Coconino sandstone appears to be relatively free from iron oxides. South of Flagstaff, however, it has a brilliant red color which is undoubtedly due to iron oxides, and along the Bass Trail in Grand Canyon are sandstone pockets whose general reddish appearance is caused by thin bands of alternating purple and white color that extend parallel to the bedding planes. Along the Hance Trail to the east—near the middle of the formation—many nodules of iron and numerous patches of iron staining are found.

At the Hance Trail locality the iron appears to be due to infiltration and concentration along fractures, but at the Bass Trail locality this is not the case. Whether the concentration there is due to original deposition or to secondary passage along pervious layers is not known, but, since the purple bands slope with the bedding, they certainly do not represent water levels. If these bands were contemporaneous with the deposition of the sand, they may have been formed in stagnant pools.

The uniform distribution of the iron oxides in the Flagstaff region suggests a different origin from those in either of the two localities just mentioned, but at the present time no source of the iron oxide has been determined.

HEAVY MINERALS

Of seven specimens from the Bright Angel Trail which were examined, each had a trace of heavy minerals—that is, considerably less than 1 per cent by weight of the total amount. The specimen that contained the greatest amount (0.17 per cent) was from the middle of the formation. The others were from various horizons. The heavy minerals are zircon, green tourmaline, blue tourmaline, leucoxene monazite, rutile, magnetite, anatase and limonite. No particular significance can be attached to any of these minerals, so far as the writer can determine, but their small total amount seems to indicate that the Coconino was derived from rather pure quartz sandstone.

FELDSPAR

Although the Coconino formation is predominantly a quartz sandstone, several samples from Grand Canyon showed, in thin section, occasional grains of feldspar. The presence of this mineral was also noted by C. S. Ross[1] who described the sandstone as "composed dominantly of quartz but contains a little feldspar."

The occurrence of feldspar in the Coconino sandstone has significance in that it may indicate either that that climate was arid, which would retard decomposition, or that the period of transportation and deposition was short, or both. Quite certainly the climate of Coconino time was at least semi-arid and probably arid as pointed out in another section (Climate, p. 110), but even so the possible distance of travel of the feldspar must have been limited by factors of decomposition. In brief, the unaltered condition of the feldspar helps to substantiate the idea that the relative purity of the quartz sand in the Coconino is due to the purity of the parent rock rather than to a long transportation, as has been supposed by some.

SIZE OF GRAIN

The size of quartz sand grains in sediments depends apparently on three factors: (1) The mode of transportation, (2) the distance of

Comparison of grain size in sands

	Total samples	Over 50 p. ct. fine grains (⅛ to ¼ mm.)	Over 50 p. ct. coarse grains (¼ mm.)	Remarks
Modern dune sands	50	43	7	
Marine sandstone	36 6 formations	9	27	Many very coarse
Coconino sandstone	30	27	3	Most have well above 50 p. ct. fine grains

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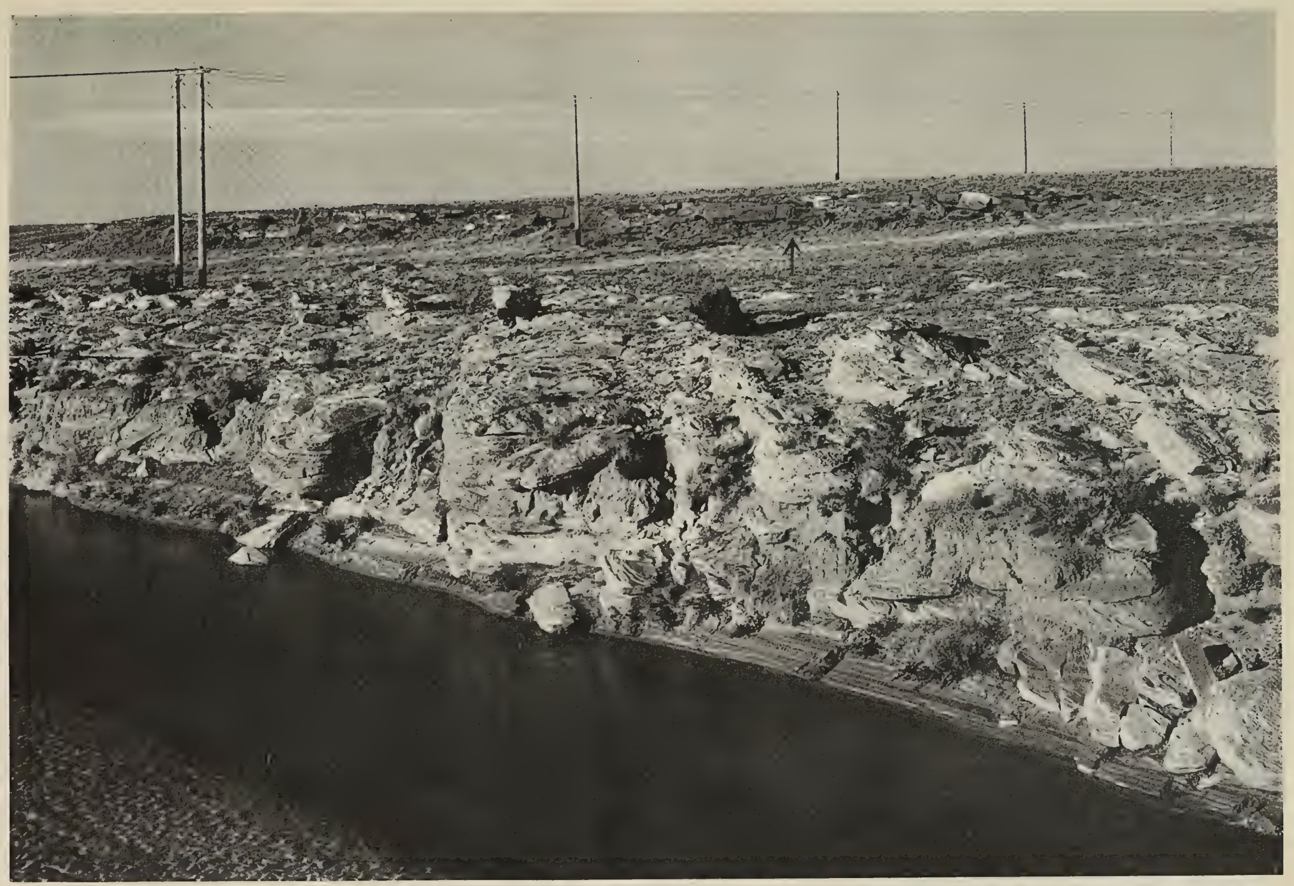
[1] C. S. Ross, in *Flora of the Hermit Shale*, by David White, Carnegie Inst. Wash. Pub. No. 405, p. 16, 1929.



Photograph by G. Grant, Courtesy Nat'l Park Service.

Moencopi-Coconino contact, east of Holbrook, Arizona.

travel, (3) the size at source. It has been definitely shown[1] that, other factors being equal, wind as a transporting agent will usually cause fineness of grain far more readily than will water. Not only does it tend to leave behind the larger grains, but also it wears and breaks up those transported. Fineness of grain, however, can not in itself be considered evidence of wind action. It is probable that water transportation over a great distance, or reworking by waves for a long time will give the same results.

Although small grains do not necessarily indicate wind action, grains transported and sorted by wind apparently are characterized by fineness under ordinary conditions. Udden[2] has shown that in fifty samples of dune sands examined, 43 had over 50 per cent fine grains (0.125 to 0.25 mm.). For comparison, sieve analyses from various marine sandstones have been compiled and also some analyses made from the Coconino sandstone (see table, page 93).

From the above table it is evident that sand grains from the Coconino formation do not differ essentially in size from those of typical wind-blown deposits of today, but average considerably finer than those of many known marine deposits. As explained above, this by itself can not be considered definite evidence of wind activity. If, however, as is believed (Paleogeography, p. 104), the source was in Mazatzal Land—a part of the great permanent land mass or "positive element" located in what is today central Arizona (fig. 5)—the distance of transportation did not exceed 200 miles. Furthermore, the size of the grains obtained from the original Mazatzal quartz sandstones, now mostly quartzites, was probably within the "coarse" group (above 0.25 mm.) as indicated by an examination of these grains (Plate 8; *a*). The combination of these facts; *i. e.* fine-grained sand derived from moderately coarse material with comparatively short transportation, seems to point to wind as the major transporting agent.

In making a study of grain sizes in different samples of Coconino sandstone, it was noted that comparatively large grains occur in samples from the region south of Flagstaff, whereas in general much smaller grains occur in samples from the Grand Canyon region to the north. The coarse-grained samples from the south, it should be added, are typical of large areas, and not from isolated bands as mentioned by Schuchert.[3] Only 4 out of 12 samples from the southern half of the formation had over 60 per cent fine grains, while all of the 14 samples from the northern half were above this limit. This apparent increase in fineness toward the north and the occurrence of some exceptionally large grains at several localities at the south seem to point to the south as the place of derivation (fig. 4). Accordingly, search was made in that direction for the source of the Coconino sand. It was found that an area of pre-Cambrian quartzites exists in the region of central Arizona known as Mazatzal Land (fig. 5) and that the Coconino sand was probably derived from this source (page 104).

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[1] C. L. Dake, *The problem of the St. Peter sandstone*, Bull. Univ. Mo., vol. 6, No. 1, p. 165.

[2] J. A. Udden, *The mechanical composition of wind deposits*, Augustana Library Pub., No. 1, 1898.

[3] C. Schuchert, Amer. Jour. Sci., vol. XLV, 1918.

Still another feature of the Coconino sandstone, brought out by a comparative study of the size of its grains, is that for any given section the grains in the upper half of the formation are noticeably finer than those in the lower half, thus indicating somewhat different conditions affecting the development of each. This fact is discussed, with the aid of charts, on pages 110 and 111.

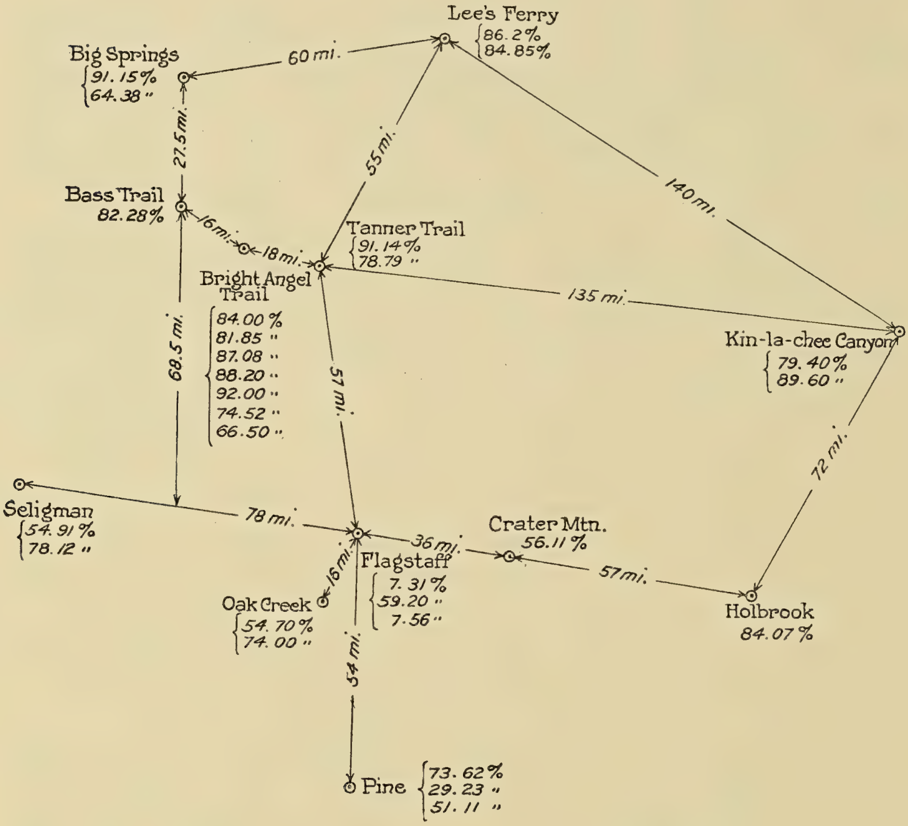
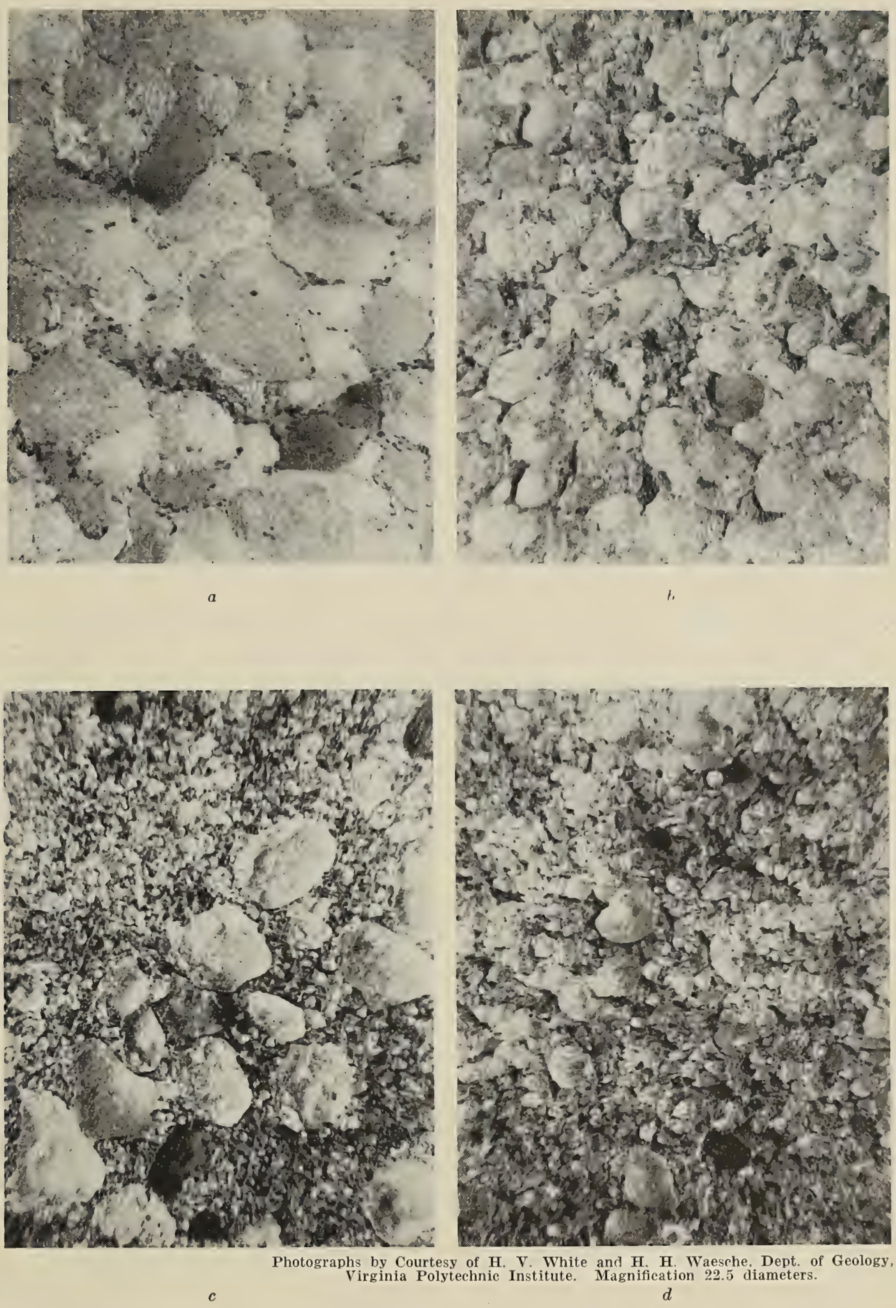


FIG. 4—Chart showing percentage of Coconino sand grains under .208 mm. in size in the Coconino.

It seems advisable here to explain the methods used in this work. Sand samples were gathered by the writer from the various localities listed and an effort was made to get typical material in every case. As far as possible material was taken from several horizons in the



Photographs by Courtesy of H. V. White and H. H. Waesche, Dept. of Geology, Virginia Polytechnic Institute. Magnification 22.5 diameters.

a. Photomicrograph of Mazatzal quartzite from southwest of Pine, Arizona.
b. Photomicrograph of typical Coconino sandstone from midway in formation, Hermit Trail, Grand Canyon, Arizona.
c. Photomicrograph of sandstone at base of Kaibab formation, Hermit Trail, Grand Canyon, Arizona.
d. Photomicrograph of Coconino sandstone from top of formation, Hermit Trail, Grand Canyon, Arizona.

upper and lower halves of the formation, so that results could be checked in later work. The sand was broken on cardboard to avoid crushing of grains and was afterward examined under microscope as a check on compound grains. The actual separation was done by a "standard" set of screens with mesh as follows: 35, 0.417 mm.; 48, 0.295 mm.; 65, 0.208 mm. The percentages of grains which were less than 0.208 mm. in size were contrasted with those above that size, since this made an arbitrary dividing point very near that designated by Udden as the limit of fine sand, and was therefore useful for comparison with his figures and those of others.

UNIFORMITY OF GRAIN

Uniformity of grain is a criterion sometimes applied to wind-blown sands and therefore should be considered here. This criterion has been applied in reference both to individual samples and to samples from the entire area. It is evident, however, that the sorting involved in either case would not only depend upon the agent, but also upon the distance of travel and the nature of the source. Even granted that wind is a better sorting agent than water (and there seems to be difference of opinion here), it does not necessarily follow that a particular sample of wind-blown sediments would be better sorted than a water-carried one. Other factors might have been very different.

The Coconino sandstone has in general been referred to as a rather uniformly grained formation. Since the amount of uniformity is a matter of comparison, however, and since the writer has no way of comparing the sand in question either with modern dune sands or with those of deltas, a proper interpretation of this feature is impossible.

The following data are presented to show the degree of uniformity of grain in the Coconino. It is not believed that these facts give any evidence of the mode of transportation or deposition, although they indicate that the sorting might have been produced by wind as readily as by any other agency. Their chief value is found in that they define a diagnostic feature of the Coconino sandstone which is useful in correlation.

In seven samples from one locality in Grand Canyon (Bright Angel Trail), the content of very fine material—clay, lime, etc.—varied between 5.1 and 11.1 per cent, but of this the amount of secondary material is unknown so that its only importance is that it shows the purity of the formation. Percentages of the fine sands have been presented in the preceding section and may be compared. Regarding coarse grains (above 0.417 mm.), it has been found that these vary (1) in a single locality in Grand Canyon between 0 and 4.8 per cent, (2) in the lower half of the formation between 0 and 15.8 per cent, and (3) in the upper half between 0 and 9 per cent.

ROUNDING, PITTING, AND FROSTING OF SAND GRAINS

The value of grain rounding as a criterion of type of deposit has been discussed by numerous writers. Those[1] who consider that it is an indication of aeolian conditions base their belief upon the greater velocities of wind and on the fact that water forms thin films which act as cushions between fine grains. Others believe that the more constant work of water makes it just as efficient an agent as wind,[2] and that time is the important feature in the rounding of grains.[3] Ries and Conant[4] conclude after making a microscopic study of the sieve separates of several hundred sands that rounding is not confined to any type of sand but is influenced to some extent by the size of the particles.

A careful study of sand grains from 26 samples representing various horizons and localities in the Coconino formation showed that practically all were either rounded or subangular. That this wearing indicates wind action, rather than water action, can not be definitely stated considering our present knowledge of this subject.

Pitting and frosting are characteristics which are found prominently on many of the sands in the Coconino formation. Ries and Conant[4] state from their examinations of sand separates that surface pitting is not confined to any type of sand, but appears to be more abundant on coarser grains wherever found. Frosted surfaces they "noticed chiefly in marine and modern dune sands . . ." but they further state that "although frosted sand grains may be abundant in formations which as now found represent marine deposits, there is a decided probability that this characteristic may be inherited from a previous and entirely different environment." On the other hand, Galloway[3] states concerning these types of surface markings that he was unable to produce them artificially through water action, thus indicating that in every case their origins probably go back to wind transportation and that they should be expected in all extensive wind deposits. Their presence on the Coconino sand grains, therefore, appears to be in accord with the aeolian origin of that formation postulated because of its extent as a homogeneous sandstone, its profile shape, its types of cross-bedding, and the wind ripples in many of its beds—features which are discussed in the following section.

STRUCTURES

Cross-bedding, ripple marks, raindrop impressions, and many other structural features in sedimentary rocks are formed during the accumulation of sediments; therefore, they are often good criteria of the *mode of deposition.* For this reason careful observations and notes concerning these structures were made by the writer during his field work and are discussed in detail in this section.

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[1] W. Mackie, *On the laws that govern the rounding of particles of sand*, Trans. Edin. Geol. Soc., vol. 7, pp. 298 to 311, 1897.

[2] C. L. Dake, *The problem of St. Peter sandstone*, Bull. Univ. Mo., vol. 6, No. 1, pp. 177 to 185, 1921.

[3] J. J. Galloway, *The rounding of sand grains by solution*, Amer. Jour. Sci., vol. XLVII, pp. 270 to 280, 1919.

[4] H. Ries and G. D. Conant, *The character of sand grains*, Paper presented at American Foundrymen's Assoc., p. 384, 1931.

EXTENT AND SHAPE IN PROFILE OF THE FORMATION

The typical Coconino sandstone extends over a vast area without any appreciable change in type of cross-bedding, purity of quartz sand, kind of cement, or general massive character. From the Mogollon Rim to the south as far as upper Kanab Canyon to the north, and from the Aubrey Cliffs to the west, as far as Holbrook and Kin-la-chee Canyon near Ganado to the east, an area of approximately 32,000 square miles, its only variation in general appearance is the previously mentioned decrease in thickness from south to north. Concerning this remarkable uniformity, Matthes[1] writes—

> "In my opinion its great areal extent, taken together with the prevailing homogeneity of the quartz sand of which it is composed, argues strongly against the probability that the Coconino formation is a delta deposit. Only a very large river draining a considerable portion of a continent could have built a delta of such vast proportions. But it is very unlikely that such a large and long river would have carried almost exclusively quartz sand out to its mouth. Most large rivers carry in their lower courses a preponderance of fine silt and clay, the coarser materials having been comminuted in the long journey down the stream. Moreover, because of its great fluctuations in volume, a large river is bound to produce more or less streaky deposits, layers of coarse material carried at flood stage alternating with layers of fine material carried at low stage. The Coconino formation, however, is notably not streaky but remarkably homogeneous, on the whole, and thus in its general make-up has not the characteristics of a river delta."

On the other hand, its areal extent and homogeneous composition are features entirely comparable to those found in certain recent sand dune areas. One-ninth of the Sahara Desert of today, about 380,000 square miles, is covered with dunes, and about 320,000 square miles (about ten times the estimated size of the Coconino formation) exists as dune area in Arabia.[2]

The shape of the profile of the Coconino formation affords further evidence regarding its origin. As already noted (fig. 1), the formation is over a thousand feet thick at its southernmost exposures, thins out gradually to the north, and disappears near the Arizona-Utah border. If, then, the Coconino formation had been a delta, its landward side would probably have been to the north or northwest since a delta, forming from the shore out into deeper and deeper water, normally is thinnest at its inner margin. As already shown, however, a study of the Coconino sand grains indicates that the source of materials was to the south. Furthermore, as has been indicated (page 89), its relations with the Kaibab formation are such as to suggest that the Kaibab Sea invaded the area from the northwest.

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[1] F. E. Matthes, Personal communication, 1932.

[2] A. W. Grabeau, *Comprehensive geology*, vol. 1, p. 450, 1920.

CROSS-BEDDING

The huge scale on which cross-bedding is exhibited by the Coconino sandstone (Plate 9) is one of its most outstanding and characteristic features. Furthermore, since the type of cross-bedding is unlike that in the De Chelly, Navajo, Wingate, or Morrison sandstones, it serves as a diagnostic character. Wherever observed this cross-bedding has been found to consist of long and sweeping layers in the upper part of the formation (often 30 to 40 feet, occasionally 75 feet long), and of shorter bedding planes below. Horizontal beds characterize the lowermost few feet. L. F. Noble describes the bedding as forming in cross-section "irregular wedges whose sides are sweeping curves" (Plate 9; *a*). All of the layers in the cross-bedding are sharply truncated by overlying layers. Each consists of many thin laminæ forming parallel curves, concave upward, which tend to flatten at their lowest ends. The angles at which the bedding planes are inclined are considerable, not infrequently ranging from 25 to 30 degrees. The surfaces on which most of the vertebrate tracks were imposed have a dip of nearly 30 degrees (Gilmore). In most localities these steep angles appear to dominate the entire formation (Plate 1). Ten miles south of Flagstaff where examined, however, the Coconino beds were steeply inclined near the base, but had only a slight angle near the top. It has been stated[1] that these surfaces slope in general to the southeast or southwest, but after careful examination in many localities the writer finds that except locally they have no dominant direction, but instead dip in various directions throughout the region.

Since the long, sloping laminæ of the Coconino formation unquestionably represent foreset beds, whether of dunes, sandbars, alluvial fans, or a delta, a brief comparison of wind- and water-formed foreset beds is here introduced. It has been shown by experiment[2] that in no case will the angle of inclination of foreset beds exceed 41 degrees. In sand dunes the usual rounding of the grains tends to lower this angle, but rapid deposition and the low density of air tend to raise the angle. Differences of momentum have little effect. In brief, as stated by Twenhofel,[3] "the angles of inclination of wind deposits are probably not greatly different from those made by water." Furthermore, features noted in the bedding of the Coconino sandstone such as the high angle of inclination at the upper end and the flattening near the base may be found in either wind or water deposits, since they are caused by removal of material from the top with accumulation

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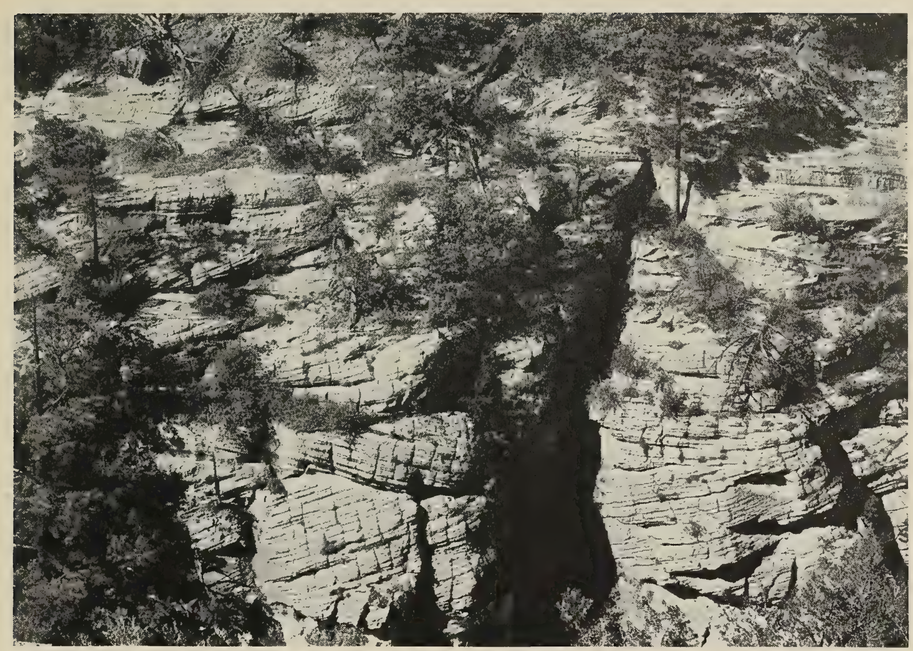
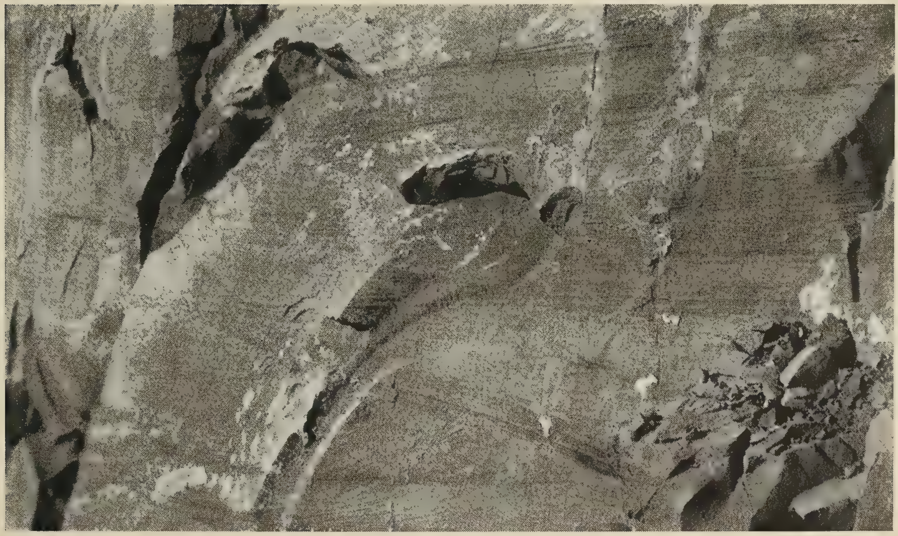
[1] C. Schuchert, Amer. Jour. Sci., Ser. 4, vol. 45, May 1918.

[2] J. Thoulet, Annales de Chemie et de Physique, 6th ser., vol. 12, pp. 33 to 64, 1887.

[3] W. H. Twenhofel, *Treatise on sedimentation*, Pub. Nat. Acad. Sci., p. 64, 1926.



a. Typical cross-bedding of Coconino sandstone showing irregular wedges and parallel curving laminæ, Walnut Canyon, Arizona.



b. Typical cross-bedding with long curving planes, upper part of Coconino sandstone, Yaki Trail, Grand Canyon, Arizona.

below, and by a lateral spreading of the basal deposits due to the weight of overlying material. The special feature of bedding by which wind-deposited sands can be distinguished from those deposited by water, according to Twenhofel,[1] is the presence in the former of "wedge-shaped, cross-laminated units with the lamination of the several units inclined in many directions." This feature is explained by the constant variation of wind currents in both direction and velocity, causing a truncation of laminations and many changes in degree and direction of the angles of inclination. It must be used with caution as a criterion, however, since "water-deposited sands, for limited extents, may show similar characteristics."[1] Nevertheless, since in the Coconino sandstone it appears consistently over a very wide area as previously described, an aeolian origin of this formation is probable.

Another important line of evidence offered by the cross-bedding of the Coconino has been suggested by Matthes[2] who states—

> "The testimony of the animal tracks on the oblique laminæ is decidedly against an aqueous origin of the Coconino formation. The foreset beds of a delta are laid down under water, their steep dip being essentially the angle of repose of the sediment under water. Hence, if the cross-bedding of the Coconino formation is assumed to consist of delta foresets, then the animals that made the footprints on the inclined surfaces must be supposed to have walked under water. However, the footprints have not the soft, vague outlines which tracks made in loose sand under water commonly have. On the contrary, they have, with few exceptions, sharp definition, even the deep impressions made by the claws of the animals being well preserved (fig. 33). If it is suggested that the tracks were made at times of low tide, when the front of the delta was partly above water, then the question arises why the tracks were not wiped out by the next high tide. It is much easier to account for the preservation of animal tracks in dune sand. True, they are readily destroyed when the sand is *dry*, but the chances for their preservation with sharp definition are particularly good if they are made after a shower, when the sand is damp enough to possess fair cohesion, and then are buried by dry sand blown over them."

The usual steepness of the beds found in the Coconino seems to imply a large supply of sand and consequently rapid deposition. This explanation seems especially necessary considering the fineness of the sediments. Furthermore, since the length of the foresets depends jointly on the rate of deposition, the velocity of the current, and outside disturbances, it seems probable that the very long bedding planes which occur throughout much of the Coconino, especially in the upper half, indicate not only abundant sand, but also a high velocity of the depositing agent with periods of constant direction.

DETACHMENT OF LAMINÆ

A characteristic of the entire Coconino formation is its type of lamination which allows separation into individual thin beds with even surfaces. Most of these surfaces are without mark or undulation of any kind, but some have the tracks of animals impressed on them.

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[1] W. H. Twenhofel, *Treatise on sedimentation*, Pub. Nat. Acad. Sci., p. 65, 1926.

[2] F. E. Matthes, Personal communication, 1932.

The detachment of one lamina from another in sandstones of uniform composition is due usually to marked differences in grain size. In a delta, this results from deposition under different conditions of flow, and in dunes from variations of wind velocity. Another cause for separation of beds in such sandstones is a variation in consistency due to different degrees of dryness or wetness.

In the Coconino sandstone the cause for the separation of the laminæ may be due either to one or to both of the conditions just mentioned. Sufficient investigations have not yet been carried on to determine the cause in many parts of the formation, but in several samples from the fossil track horizons which were examined for grain size, clay, lime and iron content, no appreciable variation was found between the upper and lower layers. This suggests that at least some of the laminæ owe their parting planes to changes in consistency, such as those which would be brought about by dry sand being deposited on moist sand.

It is apparent that the beds in the Coconino formation which contain animal tracks, rain pits, and other impressions must have been either damp or wet at the time or soon after they were formed. If the Coconino sandstone is composed of dune deposits, however, the moisture necessary for the preservation of these features must be accounted for. The occurrence of prolonged showers suggested by Mr. Matthes has already been referred to (page 99) as a likely explanation. Dr. Godfrey Sykes[1] points out from personal observations another possible source of moisture. He states that in the windswept area of the Libyan Desert he noted upon numerous occasions that the sand dunes were actually wet with dew in the early mornings. Either or both of these conditions would be especially favorable to the preservation of imprints in detail.

RIPPLE MARKS

A study of modern ripple marks shows that there are two main types;[2] the symmetrical caused by oscillatory movement of waves and the asymmetrical formed by currents. Of the latter group two varieties can be distinguished,[3] (1) the wide, low asymmetrical ripple marks formed by wind action, and (2) the narrower, higher ripple marks made by water currents. The ripple index (ratio of wave length to amplitude) gives a rather dependable means of distinguishing between these types. In wind ripples the index is above 15; in water current ripples below. The writer has verified the general

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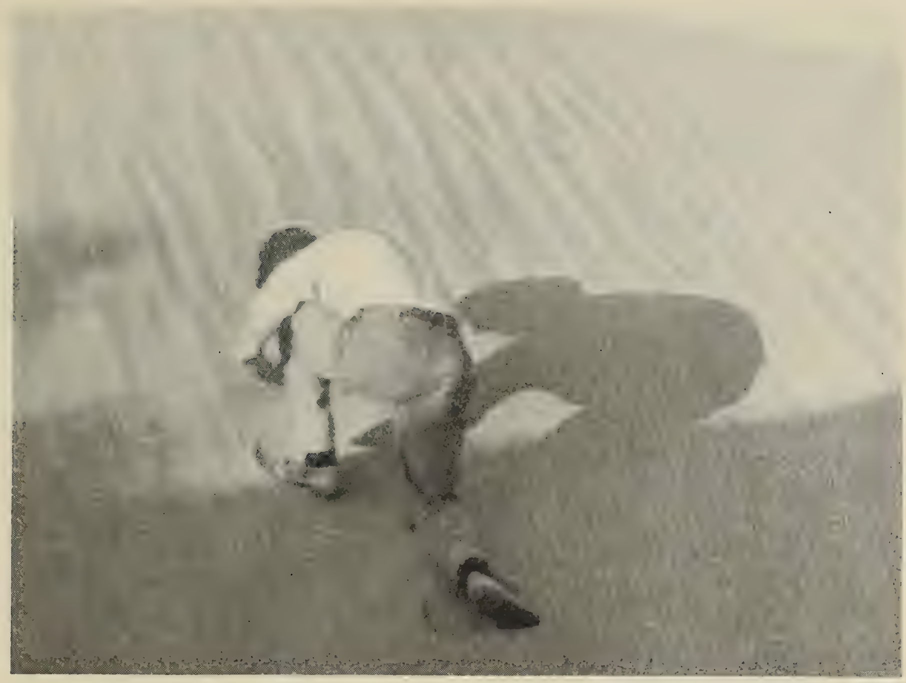
[1] Godfrey Sykes, Personal communication, 1931.

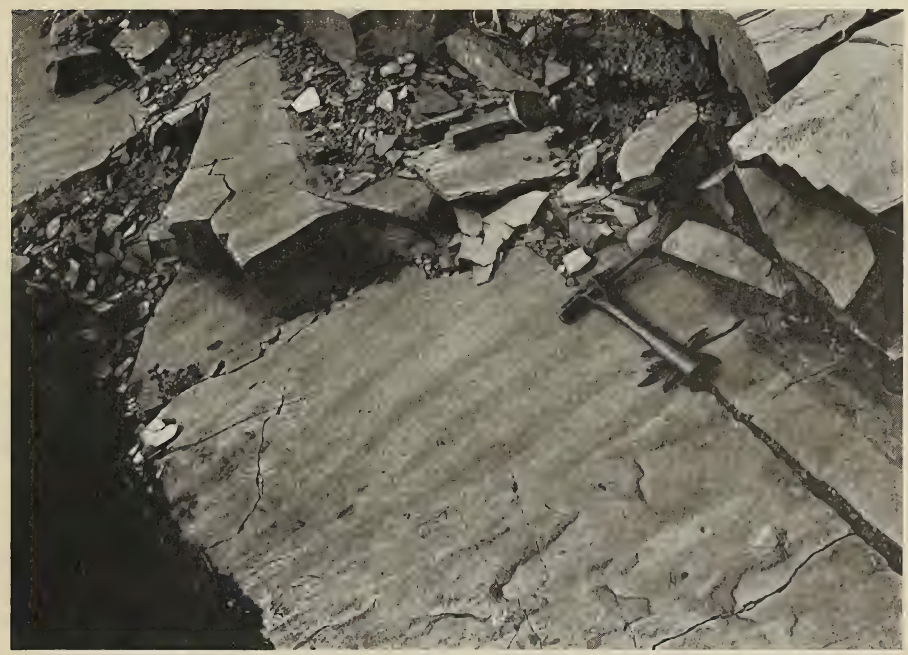
[2] Henry de la Beche, Geological Observer, 1851, pp. 87, 113, and 506 to 509.

[3] E. M. Kindle, *Recent and fossil ripple marks*, Mus. Bull. 25, Geol. Surv. Canada, p. 12, 1917.



Photograph by Courtesy of M. Schalk.

a. Modern wind ripples, Painted Desert, Arizona.



Photograph by G. Grant, Courtesy Nat'l Park Service.

b. Fossil wind ripples, Coconino sandstone, Yaki Trail, Grand Canyon, Arizona.

validity of this method of determination by the measurement of a great number of modern ripple marks of both types.

The presence of ripple marks in the Coconino sandstone was first recorded by Dr. C. Schuchert who described them as "rare, but noted on both the Hermit and Bright Angel Trails." He further stated that, "the troughs are very shallow, probably less than 5 mm. deep with the wave crests about five inches apart." These measurements give an index characteristic of wind ripples. Many similar ripples have since been found and accurately measured to substantiate this evidence, as shown in the table.

Comparison of fossil ripple marks in Coconino sandstone.

Locality	Horizon	Length	Height	Index[1]	Type	No. in series
Hance Trail	70 ft. from top	6 in.	1/8 in. to 1/4 in.	Sym.	Wave	4
Hance Trail	15 ft. from top	1 in.	1/16 in.	1–16	Wind	Numerous
Tanner Trail	Upper half	Not measured	Oscillatory	Sym.	Wave	3
Hermit Trail	90 ft. from top	6/5 in.-11/5 in.	1/5 in.	Sym.	Wave	4
Hermit Trail	100 ft. from top	6 in.	3/16 in.	1–32	Wind	3
Hermit Trail	100 ft. from top	9¼ in.	1/4 in.	1–37	Wind	2
Hermit Trail	150 ft. from top Near footprints	3½ in.- 3¼ in.	1/16 in.	1–54	Wind	6
Hermit Trail	Upper half	7 in.	3/16 in.	1–37	Wind	3
Bass Trail	100 ft. from top	4 in.	1/8 in.	1–32	Wind	14
Bass Trail	Talus at bottom	1/4 in.	Very slight	Not sym.	?	25
Yaki Trail	Definite wind ripples have been noted but never measured					
Yaki Trail	100 ft. from top	6⅛ in.	5/16 in.	1–20	Wind	21
Yaki Trail	110 ft. from top	5½ in.	1/4 in.	1–22	Wind	23
Bright Angel Trail	Talus at bottom	6 in.	3/16 in.	1–32	Wind	4

[1] All ripples with index not marked "Sym." are asymmetrical in shape.

Further evidence that certain of these ripples in the Coconino sandstone were definitely wind formed is seen in the fact that the direction of their crests and troughs is up the slope of the bedding. This feature is one found commonly on the surface of modern dunes, but is almost inconceivable as the result of water action.[1] The accompanying pictures (Plate 10) of modern and fossil wind ripples illustrate the characteristic features.

The ripple marks preserved in the Coconino sandstone are probably the most convincing evidences of its origin and clearly indicate that it was formed principally from wind-blown sand. A difficult question yet to be explained is the scarcity of the ripples. In most dune areas of today, ripples cover the sloping surfaces in great numbers. Several explanations have been suggested to answer this. C. L. Dake[2] in referring to the St. Peter sandstone states that, "the rarity of these features (ripples) is perhaps connected with the remarkable purity of the formation, there being few clay films to preserve the ripples." The same might apply to the Coconino sandstone, but this seems unlikely since all the ripples which have been found in it were preserved in and covered by sandstone layers that were essentially the same as any others in the formation. A more probable explanation is that due to the fact that the sand was for the most part dry, the necessary film to preserve most of these ripples was lacking, while the exceptions may possibly be attributed to a dampening of the sand by morning dews or by prolonged rains as discussed under *Lamination* (pages 99 and 100).

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[1] As far as the writer can determine, water-formed ripples have never been observed with their crests and troughs extending up and down with the slope of the bedding.

[2] C. L. Dake, *The problem of the St. Peter sandstone,* Bull. School of Mines and Metallurgy, Univ. of Mo., Aug. 1921.

The occasional presence of oscillatory or wave ripples and of probable water current ripples is not a contradiction of the theory of origin here proposed. They undoubtedly represent the presence of local pools or other water bodies such as might be expected in any area, especially along a coastal plain such as was probably represented by the northern part of the Coconino.

RAINDROP IMPRESSIONS

Hance Trail	Numerous pits suggestive of raindrop impressions were found about 15 ft. from top. The rims were not sharp, but were definitely present. The pits apparently were, in most cases, partially filled with sand.
Tanner Trail[1]	The impressions of raindrops (?) were found near the base of the formation.
Hermit Trail	On a slab in the upper half of the formation about 50 large pit marks ($\frac{3}{8}$ in. to $\frac{5}{8}$ in. by $\frac{3}{16}$ in.) were sprinkled. They were nearly all symmetrical. Rims such as are typical in most raindrop impressions were lacking.
Hermit Trail	Some definite raindrop impressions with imperfect rims were noted at the uppermost track horizon (150 ft. from base).

Raindrop impressions give positive evidence that the sediments containing them were not deposited beneath water. Also they suggest that origin on a beach would have been very unlikely, for impressions made under such circumstances have little or no chance of preservation. For these reasons, the discovery of rain pits in a formation eliminates the possibility of several theories of origin which otherwise might be logical explanations.

Of the four possible examples of raindrop impressions noted thus far in the Coconino sandstone, the first and last appear to be quite definite with all of the usual characteristics. The association with footprints in the last case seems very important since it indicates that the sand at that place was moist and thus perhaps better able to preserve the tracks after they have been impressed. Dry sand will readily take impressions, but it is questionable whether it will preserve them. It is interesting to note that wind ripples were found between layers containing both footprints and raindrop impressions.

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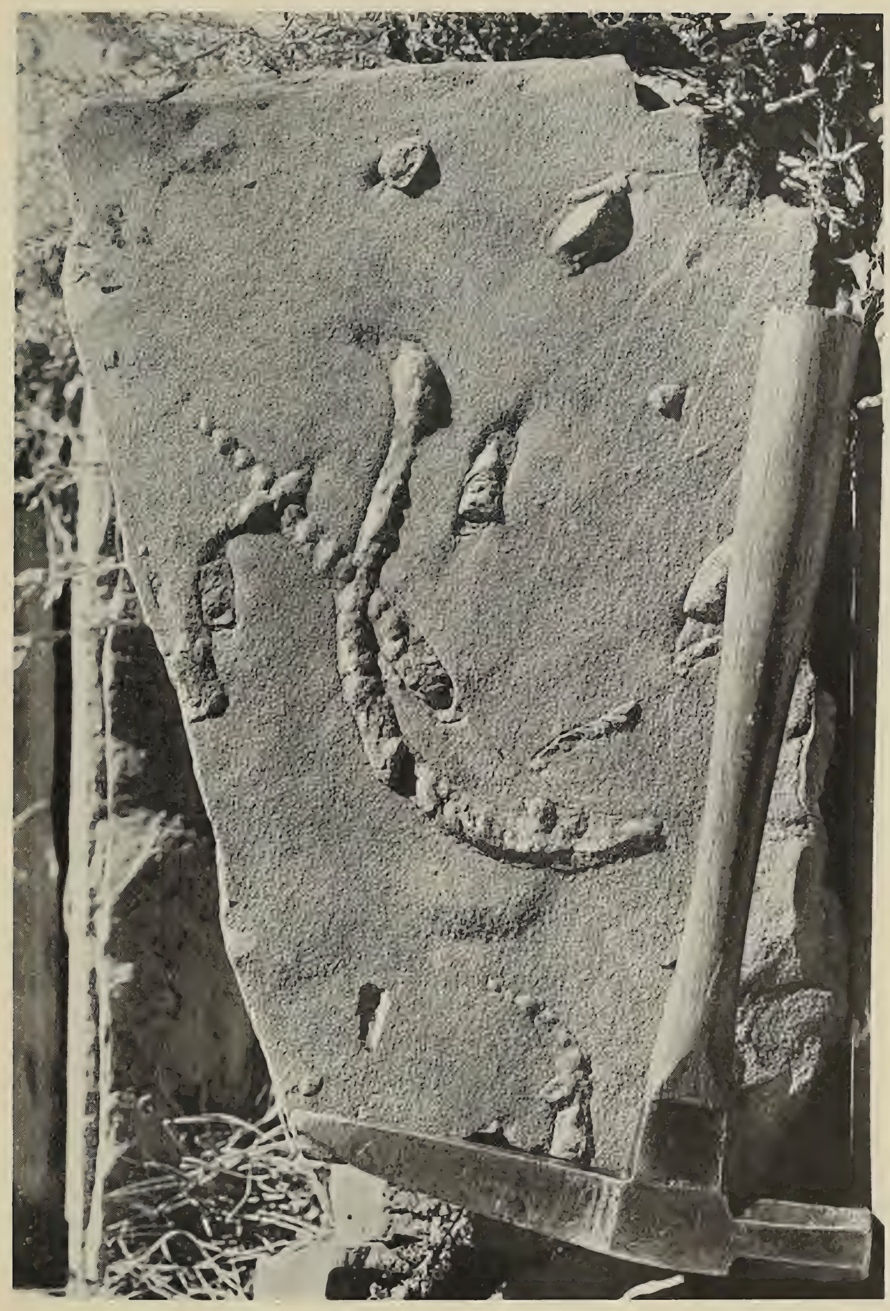
[1] Specimen not in place. All others were on the inclined surfaces of foreset laminæ.



Photograph by G. Grant, Courtesy Nat'l Park Service.

Probable coprolites found in Coconino sandstone at uppermost fossil footprint horizon, Hermit Basin, Grand Canyon.

The pits of questionable nature mentioned above can not at present be explained in any satisfactory manner.

OTHER WATER MARKINGS

Evidences of water action in the Coconino sandstone are few. Besides the raindrop impressions and the few water ripples already mentioned, some tracks have been noted in which the outlines were very indefinite—strongly suggesting the result of slumping or washing (Bass Trail, 200 feet above lower contact).

Another feature of interest was noted on the Grand View Trail. In the upper part of the Coconino sandstone, the writer found a large inclined bedding plane on which there was a succession of abrupt rises or steps of about one-tenth inch each ascending the slope. Otherwise the surface of the slab was smooth and regular. This seems to correspond to a type of mark made by waves which is described by Twenhofel[1] as, "a miniature terrace and cliff effect eroded on a beach of sand or other fine material during low tide or any stationary position of the water-level." Chances of its preservation if made under such conditions appear slight, since it would probably be washed out by the next high tide; however, the writer knows of no other explanation for its presence.

In Hance Canyon about 150 feet from the top of the Coconino and on the Hermit Trail in the lower part of the formation were noted slabs containing peculiar surface features which might be classed as "rill marks." They appeared to be irregular, nearly parallel channels, tapering on the upper sides and suggesting rills and water cuts.

While the structures described above appear to give good evidence of water action, such should be expected in any region. Their scarcity in the formation as a whole, seems to point against either beach or delta origin of this sandstone, and in most cases they might be explained by the occurrence of rains.

FUCOIDES

At one place only in the Coconino have fucoides or fucoid-like structures (Plate 11) been noted, but strangely enough this locality is the same as the uppermost track horizon of the Hermit Basin, Grand Canyon. They occur on the surfaces of several inclined laminæ. Individuals range in length between a few inches and nearly a foot; in width they average about half an inch, but they vary considerably and often taper. A few of them appear to lie on top of others, but they do not branch. Nearly all have a lumpy appearance. Several dozen of this type occur in a very limited area—perhaps not more than 10 square yards.

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[1] W. H. Twenhofel, *Treatise on sedimentation*, p. 484.

Regarding their origin—the casts of worm borings are disproved by specimens which branch but never pass through each other, by tapering ends and by the lack of any individual cutting through the inclined laminæ. Inorganic materials such as mud curls or balls resulting from shrinkage seem unsatisfactory in explanation since the Coconino is so free from clay and other fine clastics. Plant origin also seems unlikely because of the general lumpy appearance and of the probable conditions under which they were formed. Coprolites, on the other hand, seem to satisfactorily explain the peculiar shapes and to be very logically expected, considering the association with the abundant footprints of vertebrate animals.

PALEOGEOGRAPHY

As stated on page 94, a study of the textural features of the Coconino sandstone seems to indicate that the source of its sediments was to the south. A search in that direction, therefore, was undertaken with the result that a Permian land mass which might readily have supplied the fine, quartz sand grains of the Coconino was found in central Arizona. This region was the Mazatzal Land described by A. A. Stoyanow.[1] That it was a barrier between areas of deposition during Permian time was first recognized by F. L. Ransome[2] who wrote—

> "The marked difference in the Carboniferous sections of the two geographic provinces in north-central Arizona suggests that the natural barrier supposed to have existed in Cambrian time may have persisted in some form, possibly as a submarine ridge throughout the Paleozoic era."

This idea has been substantiated in the main by later paleontological work, although the Mississippian is considered to represent a time when the barrier was ineffective. On the other hand, the Kaibab deposits and fauna with which we are directly concerned, appear to have been barred from central Arizona, since no sediments or fossils that can be correlated with them have been found in that area and because the Kaibab formation thins rapidly in the direction of central Arizona.

The area included in Mazatzal Land is that which is now adjacent to and west of the Tonto Basin (fig. 5) and is composed of granites, schists and quartzites. It is a true "Positive Element"[3] and probably represents an eastern extension of the Ensenada of Schuchert[4] (southern California, northern Baja California, and western Arizona).

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[1] A. A. Stoyanow, *Notes on recent stratigraphic work in Arizona*, Amer. Jour. Sci., vol. XII, p. 314, Oct. 1926.

[2] F. L. Ransome, *Some paleozoic sections in Arizona and their correlation*, U. S. Geol. Surv. Prof. Paper 98-K.

[3] As defined by Schuchert, an area of the earth's shell which stands at a high level or apparently rises in contrast to the depressed tracts which are termed "negative elements."

[4] C. Schuchert, *Paleogeography of North America*, Bull. Geol. Soc. Amer., vol. 20, pp. 427 to 606, Feb. 1910.

In Mazatzal Land the quartzites of Algonkian age—at least 3000 feet in thickness[1] overlying the earlier Archeozoic crystallines—probably furnished the great mass of siliceous sands which are assembled in the Coconino. An examination of the geologic section (see below) shows that in the northern part, the uppermost beds consist of white quartzite (quartz sandstone in places) which may well be a remnant of the material which furnished the Coconino sand. That this material (Plate 8; *a*) may have been the source is indicated both

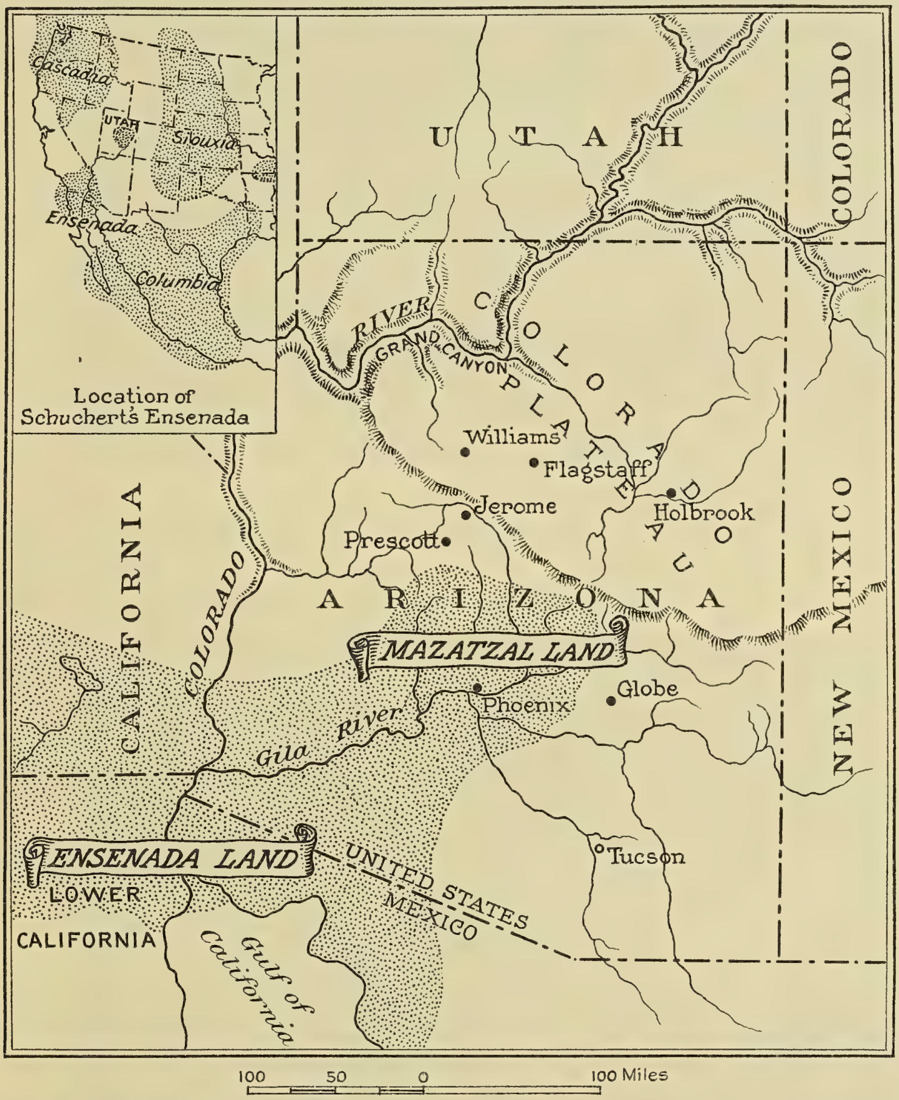

Fig. 5—Map showing probable area occupied by Mazatzal Land during the Coconino time.

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[1] E. D. Wilson, Arizona Bureau of Mines, Personal communication.

by its purity and by the similarity in size between its grains and those of the Coconino sandstone of nearby localities. The scarcity of heavy minerals in both cases makes a correlation through their use impossible. That the quartzite was in Coconino time a sandstone and thus capable of supplying sand grains is suggested by its present condition. In samples which were kindly loaned by Mr. E. D. Wilson of the Arizona Bureau of Mines, the writer was able to pry off individual quartz grains, in many cases, with a pen knife.

Section of Mazatzal Quartzite[1] *at North Peak, Mazatzal Mountains, by E. D. Wilson.*

	Feet
Quartzite, white to gray, mostly fine-grained, with some beds coarser and cross,-bedded	100
Conglomerate with pebbles up to 1 inch, quartz, jasper, feldspar, granite, schist etc.	1
Quartzite, gray, coarser than the overlying bed	140
Conglomerate	3
Quartzite, gray, massive	100
Quartzite, brown, massive	25
Quartzite, reddish, pebbly, largely cross-bedded	80
Quartzite, reddish, glassy, fine, slabby, ripple marked	250
Quartzite, pale brown, glassy, massive, cross-bedded	150
Quartzite, red, massive, with layers of spotted, maroon colored, hard shale. (Lies on pre-Cambrian schist)	100
Total	950

It is believed that during Coconino time the sea was to the west and north of the area in which the Coconino sands were being deposited. This is based on evidence given by the overlying Kaibab formation which with its Pacific fauna seems to represent a sea that encroached over the region from the west and had its southeastern limit near Holbrook. Considering the rapid thinning of the Coconino in the direction that the Kaibab thickens—from southeast to northwest—and the evidence that the unconformity between these formations represents only a brief period (page 88), it seems probable that the Kaibab Sea was already in the northwestern area, while the Coconino sands were still being deposited to the southeast.

FAUNA

FOSSIL FOOTPRINTS AND TRAILS

In the Coconino sandstone as recognized within the geographical limits established in this paper, the fossils consist, so far as known, only of the footprints of vertebrate animals and the trails of worms and other invertebrates. No remains of animals of any kind that would necessarily imply either marine or fresh-water conditions are known from this formation. It should be stated, however, that in the sandstone at Circle Cliffs, Utah, and in the Cedar Mesa sandstone of the San Juan country, which by some are believed to be extensions of the Coconino proper, marine fossils have been found.

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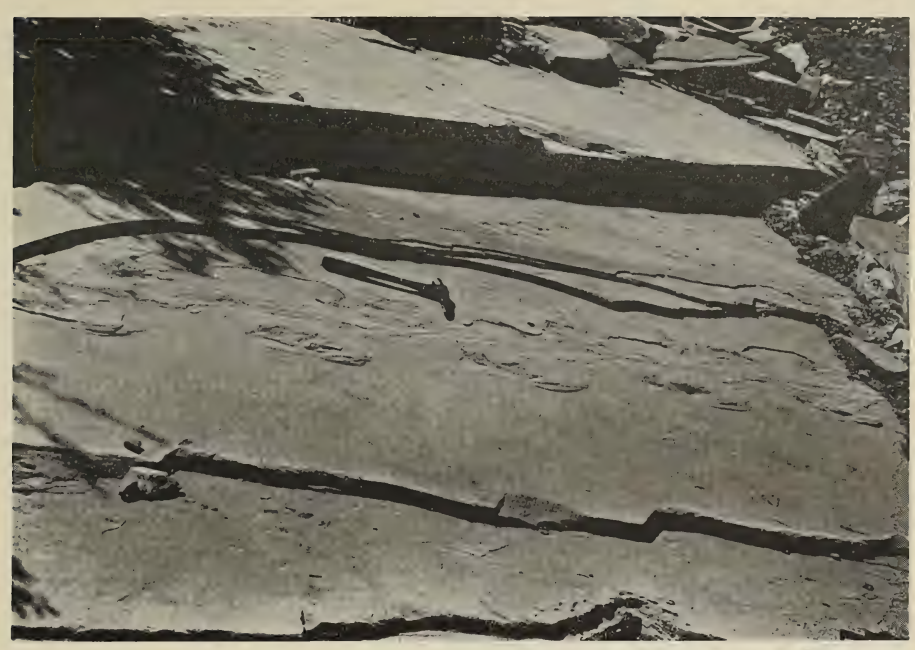
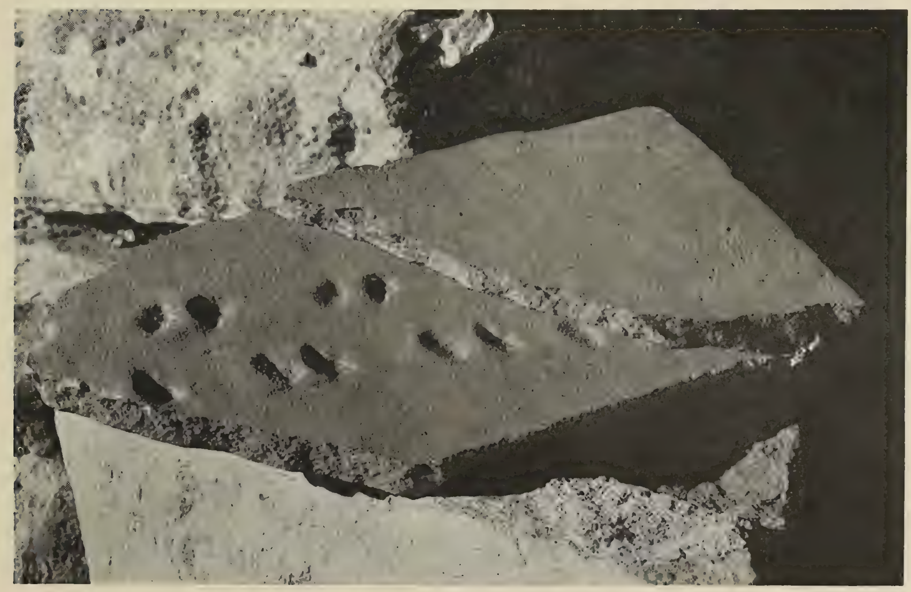
[1] The section is considerably thicker in some other localities in the Mazatzal Mountains.



Photograph by G. Grant, Courtesy Nat'l Park Service

a. Footprints of four-footed animals in place near Hermit Trail, Coconino sandstone, Grand Canyon, Arizona.



Photograph by G. Grant, Courtesy Nat'l Park Service

b. Invertebrate tracks on slab partially covering vertebrate tracks, Coconino sandstone, from Hermit Basin, Grand Canyon, Arizona.

Tracks in the Coconino were discovered in 1915 by Professor Charles Schuchert of Yale University who made a small collection along the Hermit Trail. The specimens were studied and several types described by Lull.[1] Through the interest of Dr. John C. Merriam an extensive study of the Coconino footprints by Dr. C. W. Gilmore[2] of the U. S. National Museum was made possible in 1924 and was continued for several years.

All of the Coconino footprints are considered to be those of quadrupeds, though they vary notably in size and character. Some were made, apparently, by animals not larger than small lizards, others by creatures having large feet and a stride nearly a yard in length. Some indicate short-limbed, heavy, wide-bodied animals, while others suggest those having long slender limbs and narrow bodies. The footprints occur on the upper surface of the inclined laminæ. Many of them are beautifully distinct and can often be traced for considerable distances.

Concerning the type of animals which made the tracks in the Coconino, Dr. Gilmore states that both vertebrates and invertebrates are represented. He further states[3] that the tracks of the backboned animals suggest a correlation with the Texas Permian in which occur skeletons of many kinds of extinct animals, some of which have the right proportion of foot, limb and body to have made tracks and imprints similar to those found at Grand Canyon. It seems fair to assume that similar animals formerly inhabited the Grand Canyon region. If these inferences are correct, the tracks were made by primitive crawling reptiles and amphibians, all of which are unlike any creatures living today. Burrows, believed to have been made by worms, and trails made by invertebrates, probably insects, also occur in the Coconino.

In summing up the ichnite fauna for the Coconino, Dr. Gilmore[4] states—

> "Carboniferous in aspect, as shown by the relatively small size of the animals, all of which are quadrupedal, as contrasted with the considerable number of very large forms and many three-toed bipedal animals of the Triassic. Taken as a whole, this fauna, which now consists of 15 genera and 22 species, seems to have closer relationships to the ichnite fauna from the Middle Coal Measures of Kansas described by Marsh than to the more extensive fauna from the Coal Measures of Nova Scotia made known by Dawson and Matthews."

The predominating species is *Laoporus noblei,* which apparently is present wherever Coconino tracks are found.

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[1] R. S. Lull, Amer. Jour. Sci., Ser. 4, vol. 45, pp. 337 to 346, and plates 1 to 3, May 1918.

[2] C. W. Gilmore, *Fossil footprints from the Grand Canyon,* Smith Misc. Col. Pub. 2832, 2917, 2956.

[3] C. W. Gilmore, *Fossil footprints, Nature Notes of Grand Canyon,* June 1926.

[4] C. W. Gilmore, Smith, Misc. Pub. vol. 80, No. 3, Pub. 2832, p. 73.

A peculiar feature of the occurrence of the Coconino tracks is summed up by Gilmore[1] in the following statement:

> "The trend of nearly all of the tracks and trails was in one direction, that is, up the slope of the cross-bedded sandstones—and examination of many additional hundred square feet of track-covered surface verifies this original observation. In all of the hundreds of trails seen, only three exceptions were found." At another place Dr. Gilmore refers to this feature as suggestive of, "an old trail leading to the water, or possibly . . . a great migration of animal life such as is occasionally known to take place among the animals of the present time."

The writer believes that probably this peculiar feature is not the result of any unusual condition, but that it is due to a natural coincidence between the movements of the animals and the dampness of the sand. If the parting planes of the laminæ are the results of changes in consistency caused by dry sand being deposited on moist as already indicated (*Lamination*, page 99), then the tracks on these surfaces must have been formed when the sand was damp. This dampness, whether caused by rains, dews, or any other agency, may have been the reason for the animals climbing the dunes. Tracks formed in the dry sand at other times, however, would not have been permanently preserved since parting planes were not formed under such conditions.

Regarding the lack of organic remains in the Coconino sandstone, Professor Schuchert[2] considers that this is, "probably due to the originally loose and repeatedly reworked sands, a most unfavorable habitat for animals."

The geographical range of the footprints of the Coconino sandstone is as wide as that of the formation itself. The writer has found tracks in the Coconino near Seligman, Flagstaff, Ganado (Kin-la-chee), and Lees Ferry, and along the Tanner, Hance, Grand View, Yaki, Kaibab, Bright Angel, Hermit, and Bass Trails in Grand Canyon. In the University of Arizona collections he has seen specimens from near Pine, Arizona, thus showing a very widespread and general occurrence. Tracks similar to those in the Coconino have been seen by the writer in the upper part of the De Chelly sandstone at Nazlini Canyon, suggesting the contemporaneous deposition of that formation. Lithologic and structural differences between these sandstones, however, indicate that the materials of which they are composed came from different sources and were deposited under different conditions. In the Cedar Mesa and Utah "Coconino" sandstones which have also been considered[3] as probable extensions of the Coconino or of Coconino conditions, only marine fossils have been found, so the attempt to correlate these formations does not appear to be well founded.

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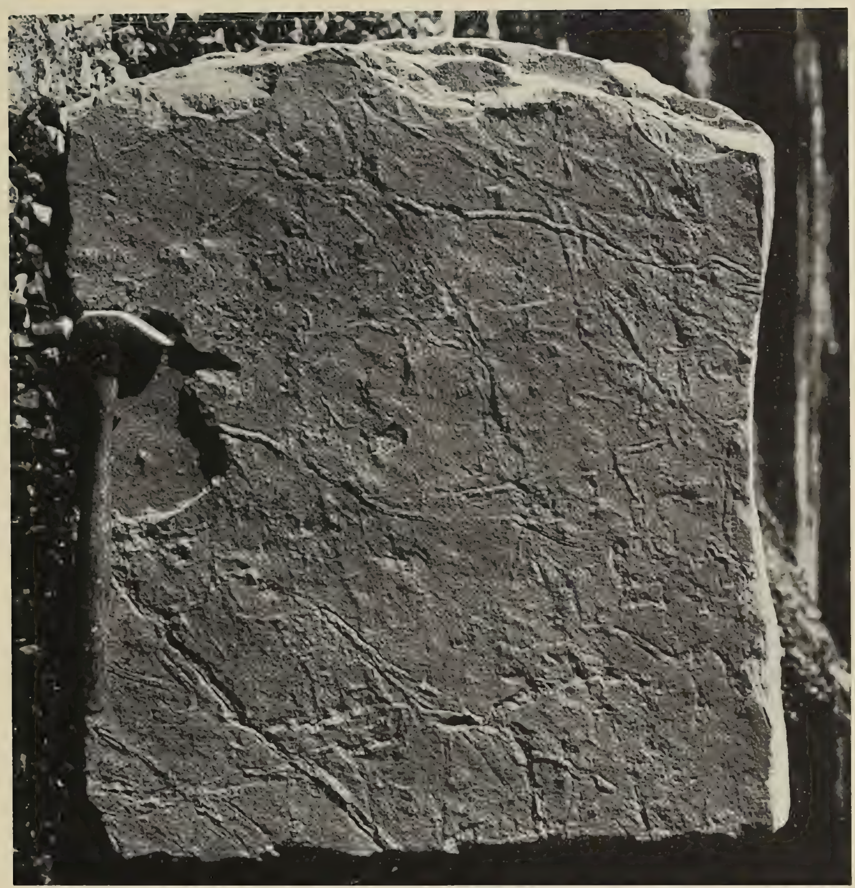
[1] C. W. Gilmore, Smith. Misc. Pub., vol. 80, No. 3, Pub. 2917, p. 3.

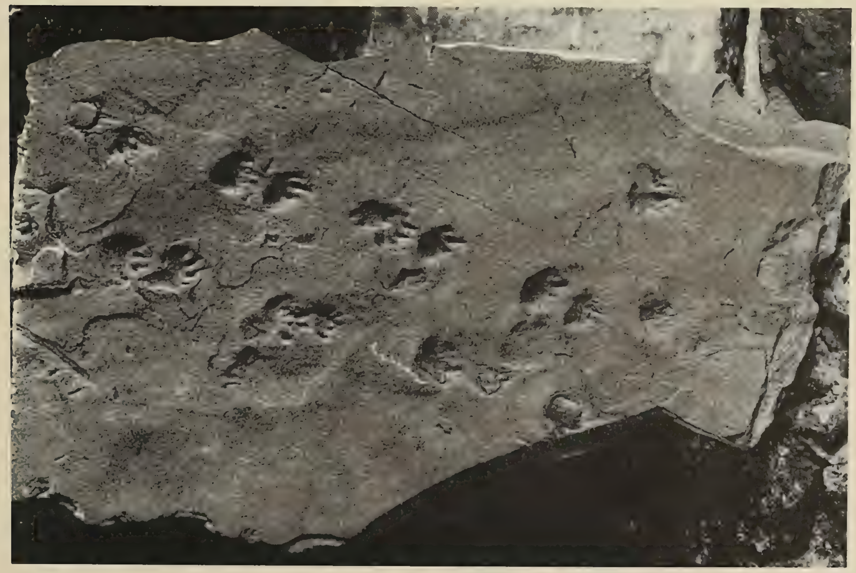
[2] C. Schuchert, Amer. Jour. Sci., Ser. 4, vol. 45, pp. 337 to 346, plates 1 to 3, May 1918.

[3] A. A. Baker and J. B. Reeside, Bull. Amer. Assoc. Petroleum Geologists, vol. 13, No. 11.



Photograph by G. Grant, Courtesy Nat'l Park Service.

a. Trails probably made by annelid worms, specimen from base of Coconino sandstone, Yaki Trail, Grand Canyon, Arizona.



Photograph by G. Grant, Courtesy Nat'l Park Service.

b. Footprints of vertebrate animal from Coconino formation, Hermit Basin, Grand Canyon, Arizona.

The vertical range of footprints in the Coconino of Grand Canyon is described by Gilmore[1] as, "confined to the basal 150 feet of the formation of which the lowermost 20 are barren," and again,[2] "so far as known (tracks) are found only in the lower half." The only exception to this that has come to the writer's attention is on the Yaki Trail where a set of tracks occurs in place about 250 feet above the base of the formation. Footprints appear to be most abundant at about the 150-foot level (about midway), but apparently occur at almost every level from there down.

The only correlation of the Coconino tracks suggested by Dr. Gilmore[3] is the following:

> "Recognition has been made of generically like if not specifically similar tracks found in the Coconino sandstone of Grand Canyon and the Lyons sandstone of Colorado."

It also seems worthy to note that Dr. Gilmore found none of the genera of the Coconino represented in the two underlying, track-bearing formations of Grand Canyon, the Hermit and Supai.

MARINE FOSSILS IN CROSS-BEDDED, PERMIAN SANDSTONES

Only three authentic records of marine fossils occurring in the Permian light-colored, cross-bedded formations of the Colorado Plateau have come to the writer's attention. Two of these[4] are from the so-called "Coconino" of Circle Cliffs, Utah. This formation, however, is believed by the writer not to be a continuation of the typical Coconino sandstone for several reasons (page 82), and is considered by Gregory[5] to represent a phase of the Kaibab limestone.

The other record of marine fossils from the light-colored, cross-bedded sandstones of the Colorado Plateau region is from the Cedar Mesa sandstone. Gregory,[6] in a description of the San Juan region, states that, "two shell fragments were found (in the Cedar Mesa)." He further states, however, that lithologic and other differences between the Cedar Mesa sandstone and the Coconino are such that they can not be considered parts of the same formation.

In brief, it is believed that the only marine fossils in the light-colored, cross-bedded sandstones of the Colorado Plateau occur in formations which are not extensions of the Coconino or of Coconino conditions.

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[1] C. W. Gilmore, Smith. Misc. Pub., vol. 80, No. 3, Pub. 2917, p. 3.

[2] *Loc. cit.*, p. 3.

[3] C. W. Gilmore, Smith. Misc. Pub., vol. 77, No. 9, Pub. 2832, p. 5.

[4] C. L. Dake, *The problem of the St. Peter Sandstone*, Bull. Univ. Mo., vol. 6, No. 1, p. 191; H. E. Gregory and R. C. Moore, *Kaiparowits Region, Utah-Arizona*, U. S. Geol. Sur., Prof. Paper 164, 1931, page 45.

[5] H. E. Gregory, *The San Juan Country*, Ms. p. 46.

[6] *Loc. cit.*, Ms. p. 46.

CLIMATE

In the table (page 110) it is seen that, in general, the grains in the upper half of the Coconino formation are considerably finer than those in the lower half. While this feature by itself may not seem to have much significance, nevertheless, it helps to corroborate the evidence obtained from three other sources which indicates that conditions of transportation and deposition were somewhat different during the forming of the upper and lower parts of the formation.

Although the Coconino sandstone is uniform throughout in general appearance, at several localities its bedding has been noted to be distinctly longer and more sweeping in the upper half than in the lower (Plate 14). Also nearly all of the wind ripples so far examined were in the upper half, while with one known exception, the fossil footprints of the Grand Canyon section have been found not over 150 feet above the base.

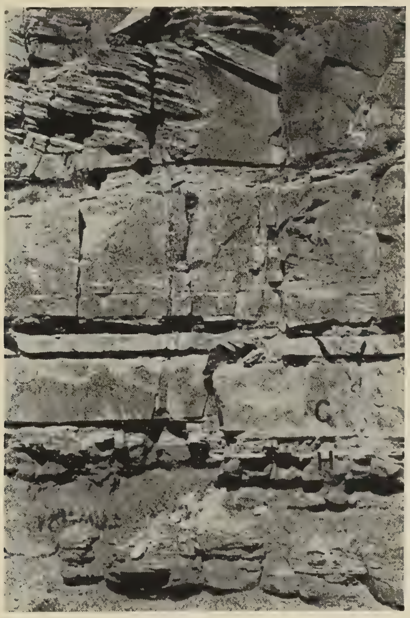
Comparison of Upper and Lower Parts of Coconino sandstone, giving percentages of sand grains under 0.209 mm.

Locality	Upper half	Lower half	Locality	Upper half	Lower half
Pine	73.62	[1]29.23	Big Springs	91.15	64.38
Pine	.....	51.11	Bass Trail	.....	82.28
Flagstaff	59.20	[1]7.31	B. A. Trail	.....	66.50
					81.85
Flagstaff	.....	[1]7.56	B. A. Trail	.....	87.08
					88.20
Meteor Crater	56.11	.....	B. A. Trail	.....	92.00
					74.52
Holbrook	84.07	.....	B. A. Trail	.....	84.00
Seligman	78.12	54.91	Tanner Trail	91.14	78.79

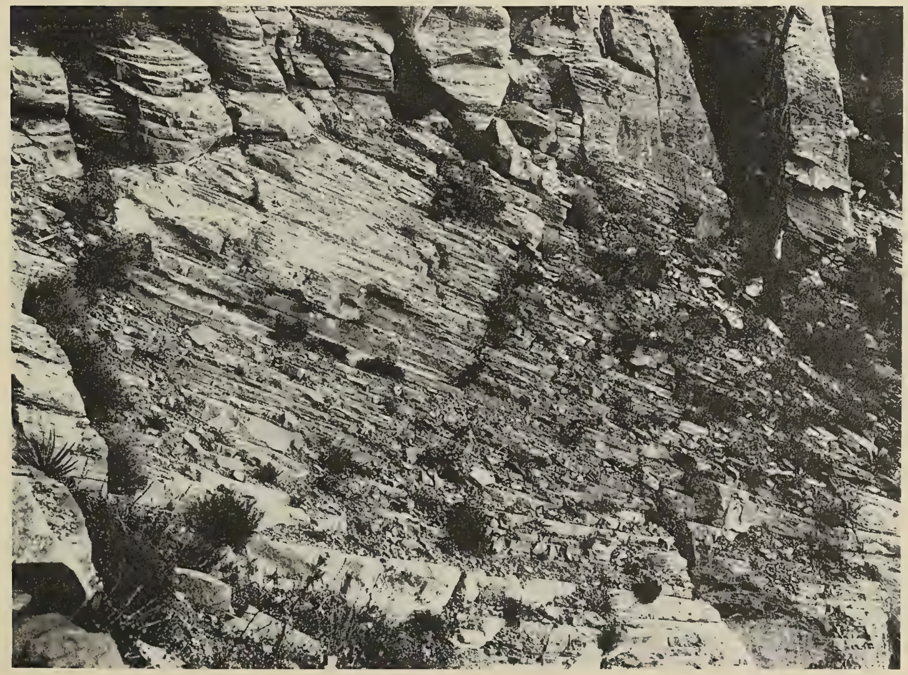
[1] The percentages of medium-sized grains (0.417 to 0.295 mm.) were 37.35, 60.72, and 59.54, respectively.

The evidence just presented seems to indicate that when the upper sands of the Coconino were being deposited, there was more wind action involved and probably far less precipitation than when the lower sands were accumulating, thus forming a less favorable habitat for animal life and at the same time causing finer sediments and more sweeping foreset beds to be deposited. Such a change, of course, would not have been sudden, but gradual as evidenced by the sediments involved.

In the Grand Canyon area the Coconino began with deposition by water, as indicated by the horizontal beds of white sandstone, ranging from 5 to 25 feet in thickness, which occur at the base of the formation. About 90 miles south of Grand Canyon (Oak Creek



a. Basal horizontal bedding of Coconino sandstone with short, steep cross-bedding, near Tanner Trail, Grand Canyon, Arizona.



Photograph by G. Grant, Courtesy Nat'l Park Service.

b. Long planes of cross-bedding near top of Coconino sandstone, near Yaki Trail, Grand Canyon, Arizona.

Canyon), however, dune deposits appear at the very bottom of the formation. In this area some of the fine red sands of the underlying red beds (Hermit?) contain cross-bedding similar to the aeolian type in the Coconino. These beds and accompanying horizontal ones of red shaly sand grade upward into the Coconino. Since there is also a vertical gradation between these formations at one place in the Grand Canyon (Tanner Trail), it is apparent that deposition was continuous throughout much of this area during the change from the conditions of Hermit time to those of Coconino.

In brief, the writer believes that the changing conditions during Coconino time were as follows. The deposition began at the close of Hermit time when the red silts and fine sands which had been brought in by rivers from the northeast, as shown by Baker and Reeside,[1] were covered by white Coconino sand which was being transported from the south by wind. Even in the beginning this sand formed dunes in the southern half of the area in which it accumulated, but farther north it was deposited by water forming horizontal beds to a thickness of 5 feet and more. In this area another change soon occurred—probably the start of dune forming—as suggested by the lowermost cross-bedded sandstones. Following this the gradual change in length of foreset beds and in size of sand grains, described in the preceding paragraphs, suggests a progressive decrease in the part played by water and an increase of wind activity, possibly the result of a climatic trend toward extreme aridity. The Coconino finally ceased to be formed as the Kaibab Sea encroached upon it—beveling its uppermost sloping (foreset) beds and reworking the soft sand of its surface.

During Hermit time the climate is considered to have been semi-arid[2] because of the molds of salt crystals, the many large sun cracks, and type of flora found in its deposits. Since Coconino time immediately followed, its climate at the start probably was somewhat similar although it became progressively more arid as indicated by the changes from bottom to top of the formation already mentioned. The dune deposits, wind ripples, and the occasional grains of undecayed feldspar, all of which are found throughout the Coconino, indicate that it was formed in a desert stretching inland from the sea, probably 200 miles or more. Of course, dunes and wind ripples can be formed in humid regions, as for example in northern Indiana, northwestern France and eastern Prussia, but then they are the results of on-shore winds. In the case of the Coconino, however, the dominant wind, as indicated by the direction of transportation of the sand grains, was from south to north or toward the sea, hence desert conditions are postulated for this formation.

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[1] A. A. Baker and J. B. Reeside jr., Bull. Amer. Assoc. Petroleum Geologists, vol. 13, No. 11, p. 1446, Nov. 1929.

[2] David White, *The flora of the Hermit shale*, Carnegie Inst. Wash. Pub. No. 405, 1929.

SUMMARY

Age—The Coconino sandstone, which in its type locality at Grand Canyon occurs between the plant-bearing Hermit shale and the marine Kaibab limestone, probably was formed during the middle of the Permian period. According to Dr. David White, the flora of the underlying Hermit shale is the upper Lower Permian. Deposition of the Coconino soon followed that of the Hermit shale, as may be inferred from the grading contact seen near the Tanner Trail, Grand Canyon. The interval between the deposition of the Coconino and that of the overlying Kaibab formation of Permian age, likewise, probably was not great, for there is an absence of erosional features at the top of the Coconino and the remarkably horizontal contact suggests that the uppermost Coconino beds were merely beveled and reworked in an unconsolidated form with the encroachment of the Kaibab Sea.

Area—The area covered by the Coconino sandstone is approximately 32,000 square miles. The formation thins to extinction along its northern boundary which is near the Arizona-Utah border. To the west, it is recorded as very thin in the Virgin Mountains, but occurs southeast of there with a thickness of 700 feet in the receding Aubrey Cliffs. Its entire southern boundary is marked by the limits of the Colorado Plateau where it attains its maximum thickness of 1000 feet. To the east it is found near Holbrook and at Kin-la-chee Canyon near Ganado beyond which it grades laterally into the upper part of the De Chelly sandstone of Fort Defiance and Nazlini Canyons. The De Chelly sandstone differs from the Coconino in type of cross-bedding, mineral content, grain sizes, and type of cement; therefore, although of the same age, it is considered to have been formed under different conditions and of material derived from another source. The Cedar Mesa sandstone and the so-called "Coconino" of southern Utah likewise are believed not to be extensions of the Coconino or of Coconino conditions, since they are unlike it lithologically and contain a different type of fossils and of cross-bedding. Furthermore, the typical Coconino is known to thin and disappear toward the northeast where these formations occur.

Source—A comparative study of the sand grains in the Coconino formation shows that they are predominantly medium coarse grained at the southern limits of the formation, but that in general they grade into much finer material to the north. In brief, only four out of twelve samples from the southern half of the formation contained more than 60 per cent fine grains, while all of the fourteen samples from the northern half were above this limit. The only reasonable interpretation is that the source of the material lay to the south. This would suggest that the sand came from the "Positive Element" known as Mazatzal Land in central Arizona, which is known to have been a barrier between areas of deposition during Permian and most of the earlier Paleozoic time. A study of the rocks of this area shows that the widely distributed white Algonkian quartzite probably furnished the material. Even now the quartzite is not entirely metamorphosed, and both its grain size and purity closely resemble the Coconino sand. The fact that this source was near the southern limit of the Coconino checks with evidences of short transportation furnished by the presence of well-preserved feldspar as far north as Grand Canyon. The lack of pebbles in the Coconino is probably due to the fact that wind was the major transporting agent.

Transportation—Direct evidence of the type of transportation of the Coconino sands is not abundant. Grain size, uniformity of grain, clay, carbonate, iron content, heavy minerals, and rounding of grains apparently give no conclusive evidence. Pitting and frosting, which are very apparent on many grains, show that those grains, at least, have been wind transported, although not necessarily during Coconino time. More significant is the excellent evidence which has been found of the type of transportation (also deposition) in the great extent of the homogeneous quartz sand of the Coconino and in the profile shape of the formation. These features when considered in connection with the probable source of materials and the location of the sea suggest rather convincingly that it was formed as a dune area and not a delta. Furthermore, since much of the actual deposition was definitely of aeolean nature as shown by the presence of wind ripples and other features described under *Deposition*, it seems reasonable to assume that the wind was also a prominent agent in transportation.

Deposition—That the Coconino sands were deposited in large part by wind is shown by the wedge-shaped, cross-bedded units which, with their laminations, are inclined in many directions (a feature produced by water only in limited areas). Also aeolean deposition is indicated by the shapes and index measurements of the ripple marks found in this formation. Further evidence occurs in the almost entire lack of washing or slumping of the vertebrate footprints preserved in it. These have all been found on the sloping surfaces of the cross-bedding which represent foreset beds either of a delta or of dunes. If formed in a delta, they were deposited under water so the tracks on them would be washed. On the other hand, if they represent dune surfaces, it seems improbable that the dry sand would have preserved the tracks. To explain their presence, therefore, a dampening of the sand through rains, heavy dews (such as are known to occur in deserts of today), or similar agencies have been suggested. Evidences of water action have been found at a few places in the Coconino in the form of oscillatory ripples, probable raindrop impressions, and drainage or rill marks. The raindrop impressions also show that the sands could not well have been deposited on a beach, since they would then have had little or no chance of preservation.

The steepness of the beds in the formation together with the fineness of sand suggest rapid deposition from a large supply of materials. Great velocity of the depositing agent is suggested by the extreme length of some of the beds, since this depends on rate of deposition, velocity of current, and outside disturbances.

Fossils—The animals responsible for the footprints in the Coconino, according to Gilmore, were either amphibians or reptiles, but no evidence concerning the environment is furnished by this knowledge. No skeletal remains have been found, probably because the originally loose and repeatedly reworked sands formed a most unfavorable habitat for animals. The only records of marine fossils ascribed to the formation are from the sandstone at Circle Cliffs, Utah, and from the Cedar Mesa sandstone of Monument Valley whose correlation with the Coconino is considered invalid.

Change of Conditions—The upper and lower halves of the Coconino formation apparently represent somewhat different conditions. In the lower part the sand grains are coarser, the bedding planes are shorter and steeper, and almost all of the footprints occur. In the upper part of the formation have been found most of the known wind ripples. This gradual change to an environment, which apparently formed a very unfavorable habitat for animals, was brought about, it is believed, through an increase in wind activity, and a progressive desiccation—possibly a climatic trend toward extreme aridity. In brief, Coconino sands are considered to be those of a desert which gradually became more arid from Hermit to upper Coconino time.

Sea during Coconino Time—An encroachment of the Kaibab Sea from the west and north probably followed immediately upon the deposition of the Coconino. Indeed, judging from the directions of thinning in the two formations, the basal Kaibab sands and limes may have been accumulating in the northwestern part of the region at the same time that the Coconino sands were forming the top part of that formation to the east. This is further indicated by the lack of erosional features in the top of the Coconino and by the extremely level contact, suggesting that the uppermost Coconino beds were merely beveled and reworked in an unconsolidated form with the encroachment of the Kaibab sea.

General—In summary, the area in which the Coconino sandstone was formed is pictured as a low, flat region with the sandstones or quartzites of Mazatzal Land to the south supplying sands which were deposited largely by wind over the surface of red Hermit muds. From the north and west, an epicontinental sea gradually encroached upon and finally covered the region.

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VIII

A RODENT FAUNA FROM LATER CENOZOIC BEDS OF SOUTHWESTERN IDAHO

By Robert W. Wilson

With two plates and eight text-figures

[Issued December 1933]

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A RODENT FAUNA FROM LATER CENOZOIC BEDS OF SOUTHWESTERN IDAHO

INTRODUCTION

The late Pliocene or early Pleistocene continental deposits occurring in southwestern Idaho have yielded scattered fossil mammalian remains during the past forty years or more. However, with the exception of beaver material described as *Castor accessor* by O. P. Hay nothing has been recorded concerning the rodents from these beds. That a diversified assemblage of types occurs in these later Cenozoic sediments is clearly shown by collections procured in recent years in the course of palæontological explorations along the Snake River near Grand View and Hagerman, Idaho.

The westerly of the two principal localities in this region of Idaho is situated on the west side of the Snake River approximately thirteen miles northwest of the town of Grand View. This site was investigated by the California Institute of Technology. The Hagerman locality, where extensive excavations were conducted by the United States National Museum, is situated on the Snake River across from the town of Hagerman. In an airline, the distance between the localities at Grand View and Hagerman is approximately sixty miles.

The United States National Museum has generously permitted me to borrow the rodent collections obtained by that institution at the Hagerman locality. The beaver remains were not included, since important studies of this group are being conducted elsewhere. The present paper embraces therefore a study of the rodent types now known from the Hagerman and Grand View localities, with the exception of the material noted above, and grateful acknowledgment is made here for opportunity to study the National Museum collections. Recent comparative material was loaned by the Division of Vertebrate Zoology, California Institute. The illustrations of the rodent material were prepared from photographic enlargements by John L. Ridgway. The author also wishes to thank Dr. Chester Stock for opportunity to study the California Institute collections and for supervision of the work, as well as for a critical reading of the manuscript.

AGE RELATIONSHIPS OF FAUNA

The following rodents are now known from the Grand View and Hagerman localities:

† Citellus? species.
† Thomomys gidleyi n. sp.
*, ? † Castor cf. accessor Hay.
* Synaptomys vetus n. sp.
† Mimomys (Cosomys) primus (Wilson).
* Mimomys? parvus n. sp.
* Ondatra idahoensis idahoensis n. sp., n. subsp.
† Ondatra idahoensis minor n. subsp.

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* Grand View locality.
† Hagerman locality.

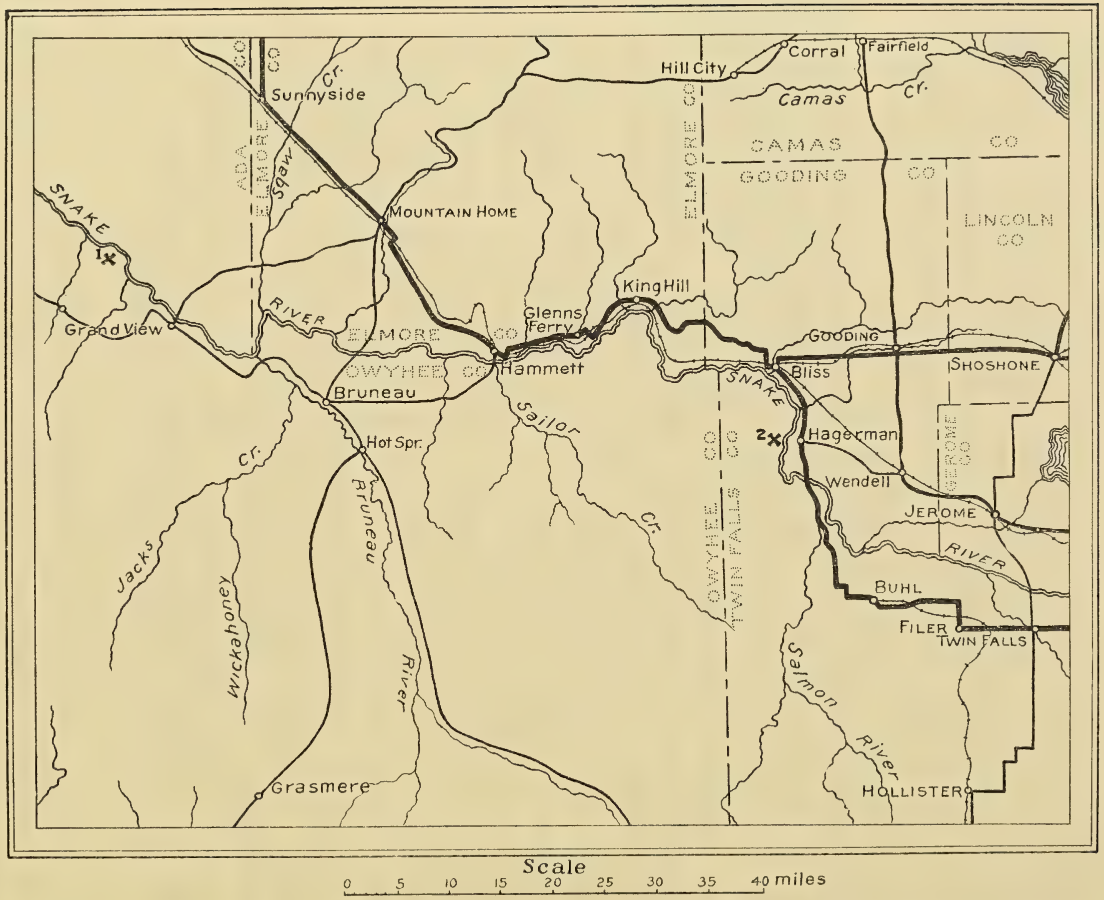

FIG. 1—Index map of a portion of southwestern Idaho, showing location of fossil vertebrate occurrences near Grand View (^{1}X), and Hagerman (^{2}X). From road map of Automobile Club of Southern California.

Only a limited number of comparisons with related faunas can be made, since rodent assemblages from the uppermost Pliocene or lowermost Pleistocene in North America are at present very imperfectly known.

The type of *Mimomys primus*[1] occurs in upper Pliocene beds of the Coso Mountains, California. Since the known history of the vole group appears to indicate a rather rapid change in certain structural details of the dentition in these types during the upper Pliocene and lower Pleistocene, the presence of the same species at localities in California and Idaho may be of some importance in assisting to establish a correlation between the two deposits. Unfortunately, no other rodents are known from the locality in the Coso Mountains.

A rodent collection described by Gidley[2] from later Cenozoic deposits in San Pedro Valley, Arizona, and referred to a late stage of the Pliocene, includes an incomplete upper second molar assigned by that author to the genus *Neofiber.* This tooth is characterized by the presence of small roots, in which respect it differs from teeth in Recent specimens of the genus. In this character and in that of size, the San Pedro Valley specimen agrees apparently with *Ondatra idahoensis* from the Idaho beds. No other rodents common to both localities have been discovered.

Mimomys pliocænicus from the upper Pliocene of Europe presents a stage of evolution closely comparable to that of *Mimomys primus.* In England this species ranges from the Norwich Crag to the shelly crag of lower Cromerian or Weybourne Crag age, at East Runton.

In the present state of our knowledge, an exact determination of age based on the relationships of the Idaho rodent fauna can not be made. However, available evidence indicates a stage of development not earlier than upper Pliocene or later than middle Pleistocene. Presence of *Mimomys primus* in the Hagerman fauna points to an upper Pliocene or lower Pleistocene age, more probably to the former.

The faunas from the Grand View and Hagerman localities may not represent exact equivalents in time, but there can hardly be any considerable hiatus between them.

ENVIRONMENT OF FAUNA

The rodent assemblage appears to offer evidence of value in an interpretation of the ecologic conditions prevailing during the accumulation of the later Cenozoic beds in southwestern Idaho. Presence of beavers and muskrats suggests the close proximity of fresh water, perhaps an ancient lake or a predecessor of the present Snake River. The occurrence of a lemming and of several species of voles also points to the prevalence of rather moist conditions and to the presence of abundant grasses. Remaining elements in the fauna, namely a sciurid and a gopher, do not offer any noteworthy suggestions as to the ecologic conditions that prevailed.

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[1] R. W. Wilson, Jour. Mamm., vol. 13, 150-154, 1932.

J. W. Gidley, U. S. Geol. Surv. Prof. Paper 131, 119-128, 1922.

SYSTEMATIC DESCRIPTION OF SPECIES

Citellus? species

Included in the material from Hagerman is a right lower fourth premolar of a sciurid type (Pl. 1, fig. 6), No. 12963 U. S. Nat. Mus. This specimen probably represents a species of *Citellus* in the broader sense and as included in such doubtful genera as *Callospermophilus* and *Otospermophilus*. No. 12963 resembles the comparable tooth in the latter genera decidedly more so than it does that in typical *Citellus*.

The Idaho citellid differs from specimens of *Otospermophilus beecheyi beecheyi*, the Recent California ground-squirrel, in slightly more marginal position of the cusps, in presence of a U-shaped rather than a V-shaped notch between paraconid and internal rim of talonid, in greater definitiveness of paraconid and protoconid, and in smaller size. No. 12963 differs somewhat from specimens of Recent *Callospermophilus lateralis certus* in the more U-shaped notch between paraconid and internal rim of talonid, and in the slightly greater separation of paraconid and protoconid. No. 12963 is slightly larger than $P\bar{4}$ in Recent specimens of *Callospermophilus*.

The Idaho specimen is distinctly smaller than either of the two fossil citellids described by Gidley[1] from the San Pedro Valley beds. *Citellus cochesii* apparently possesses somewhat broader teeth, while *Citellus bensoni*, agreeing with *Otospermophilus beecheyi* except for slightly better defined valleys and cusps, differs probably in one or more of the characters stated above in a comparison of the form from southwestern Idaho with the modern species.

Measurements (in millimeters)

$P\bar{4}$, anteroposterior length	1.7
$P\bar{4}$, transverse width	2.0

Thomomys gidleyi n. sp.

Locality—Hagerman, Idaho.

Type—No. 12651, U. S. National Museum, an incomplete left ramus bearing $P\bar{4}$ and $M\bar{1}$ (Pl. 1, figs. 4, 4a).

Specific characters—First lower molar narrowing gradually toward internal side instead of being rather abruptly constricted as in living species of *Thomomys*. Size small, approximately that in Recent *Thomomys quadratus quadratus*.

Remarks—Apparently but two well-established extinct species of the genus are known from the Pleistocene of North America, namely, *Thomomys orientalis* of Florida and *T. microdon* of California, both from cave deposits. Unfortunately these types are represented only by skull fragments. Since rami are unknown, a comparison with the Idaho specimen is limited to the character of size. *Thomomys orientalis* is a larger form than the Idaho species, while *T. microdon* apparently resembles *Thomomys gidleyi* in size.

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[1] J. W. Gidley, *ibid.*, 121-122, 1922.

The lower premolar of *Thomomys gidleyi* corresponds to that in examined specimens of Recent *T. quadratus quadratus, T. monticola mazama* and *T. fuscus fuscus* in the somewhat elliptical shape of the anterior lobe and in the size of angle made by the intersection of the principal axis of the lobe and the major axis of this tooth. In disposition of the anterior enamel band on P$\overline{4}$, the Idaho specimen differs somewhat from normal specimens of the several species mentioned above. In *T. gidleyi* this band is confined to the anterior face of the tooth, whereas, in the Recent species referred to, the anterior enamel band usually extends to the internal face of the lobe. However, a ramus of *T. monticola mazama* shows a P$\overline{4}$ in which the enamel is confined to the anterior face. Furthermore, the internal wall of the anterior lobe is commonly slightly concave in Recent forms instead of straight as in the Idaho specimen. This character also appears to be subject to variation. Evidently in shape of M$\overline{1}$, the Idaho type presents a character distinguishing it from known species of *Thomomys*. The first lower molar of *T. gidleyi* narrows gradually toward the inner side, in which respect it differs from the comparable tooth in all other specimens of *Thomomys* examined, where the inner side of the tooth is abruptly constricted.

Measurements (*in millimeters*)

	Anteroposterior diameter	Transverse diameter
P$\overline{4}$	1.9	1.6
M$\overline{1}$	1.2	1.8

Castor cf. accessor Hay

Locality—Grand View, Idaho.

Material—A fragment of ramus with M$\overline{1}$, No. 1360 Calif. Inst. Tech. Coll. Vert. Pale. (Pl. 1, figs. 3, 3a); several isolated cheek-teeth (Pl. 1, figs. 1, 1a, 2, and 5); and two distal fragments of humeri.

Remarks—The beaver material from the locality at Grand View is referred to the genus *Castor* because of close resemblance in tooth pattern between the Idaho form and the modern genus. However, the material certainly represents a type distinct from any living species of *Castor* in the less persistent hypsodonty exhibited by the cheek-teeth. The pulp cavities of the cheek-teeth are closed and roots have formed in a number of the fossil specimens. In Recent *Castor*, roots are developed rather late in life, apparently somewhat later than in the Idaho form. Moreover, the external lateral grooves in the upper cheek-teeth and the internal lateral grooves in the lower cheek-teeth are closed at the base and have retreated from the base of the crowns for varying distances, except in very young specimens. Closing of the lateral grooves is apparently to be considered as a first step in the cessation of growth of crown and in the formation of roots in these teeth. Hence, the presence of closed grooves in all but the youngest specimens suggests a less hypsodont crown in teeth of the Idaho form than in those of Recent *Castor*. In the latter the lateral grooves apparently are not closed until a late stage has been reached in the life of the animal.

Castor accessor,[1] described by O. P. Hay, was found in beds of later Cenozoic age near Caldwell, Idaho. The type and apparently only described specimen is a P$\overline{4}$. Unfortunately this particular tooth is not represented in the Grand

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[1] O. P. Hay, Carnegie Inst. Wash. Pub. No. 322B, 266-267, 1927.

View collections. However, the beaver from the latter locality possesses teeth nearly comparable in size to the type of *C. accessor*, although considerable variation in this character is exhibited by the available material from the region of Grand View. The type of *Castor accessor* is little worn and the internal lateral grooves extend to the base of the tooth. A similar feature exists in a specimen from Grand View, No. 1386 Calif. Inst. Tech. Coll., in which the crown is unworn. Whether or not the stage of hypsodonty seen in Recent *Castor* is more closely approached by the type of *C. accessor* than by the specimens from Grand View can not be satisfactorily determined.

The description and illustrations of *Castor californicus*[1] from the Etchegoin formation of the Kettleman Hills, California, do not suffice for full comparisons with the Idaho material. If the Californian type represents M$\underline{2}$, as determined by Miss Kellogg, it can be distinguished from the Idaho specimens by greater elongation of crown. However, the recognition of this tooth as a second upper molar may not be correct. *Castor californicus* appears to represent a somewhat smaller species than *C. accessor*, although the variation in size exhibited by both forms is not known.

Beaver material has been recorded also from the Hagerman locality.

Measurements (in millimeters)

	Anteroposterior diameter*	Transverse diameter*
M$\underline{1}$	9.5	10.2
M$\underline{2}$	7.7	10.0
M$\underline{3}$	7.6	8.2
M$\overline{1}$	8.0	7.9

* Measured at occlusal surface.

Synaptomys vetus n. sp.

Locality—Grand View, Idaho.

Type—No. 1364 Calif. Inst. Tech. Coll. Vert. Pale., a fragment of jaw with right M$\overline{1}$.

Paratypes—No. 1365, a right M$\underline{1}$; No. 1366, a right M$\underline{2}$; and No. 1367, a right M$\underline{3}$.

Referred material—No. 1368, a fragmentary right ramus without incisor or cheek-teeth; a number of isolated cheek-teeth and incisors.

Specific characters—Closed triangle absent on external side of M$\overline{1}$. A rather deep, second external re-entrant angle[2] present on M$\overline{1}$. Size resembles that of Recent *S. borealis wrangeli.*

Description—The referred upper incisors are grooved near their outer borders. Behind the convex chisel edge, when unbroken, is frequently developed a deep excavation due to the rapid wearing away of the soft dentine. It is to be noted that the genus *Synaptomys* is the only lemming possessing distinctly grooved upper incisors, although traces of grooves are sometimes present in the upper incisors of *Lemmus*. The lower incisor is wholly lingual in position and apparently terminates at a point situated slightly in back of the anterior margin of $M\overline{3}$. The cheek-teeth possess cement but are without roots.

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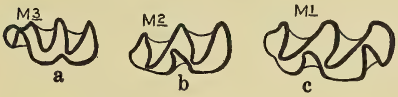
[1] Louise Kellogg, Univ. Calif. Pub., Bull. Dept. Geol., vol. 6, No. 17, 401-402, 1911.

[2] In describing the cheek-teeth of this and of the microtine species which follow, the system used by M. A. C. Hinton for enumeration of the re-entrant and salient angles has been adopted. See Hinton, *Monograph of the voles and lemmings (Microtinæ) living and extinct*, vol. 1, 22, 1926. To quote from Hinton: "In describing the teeth it is customary to enumerate the salient angles and re-entrant folds from before backwards in upper molars, and from behind forwards in lower molars, the first salient angles on each side being formed by the transverse loop."

The pattern of $M\underline{1}$ (fig. 2c) consists of an anterior loop and four alternating triangles. The external re-entrant angles are much deeper than the internal re-entrants as is the case in all of the superior cheek-teeth with the exception of the second internal re-entrant angle of $M\underline{3}$. The pattern is essentially the same as in the corresponding tooth of Recent *Synaptomys borealis*. $M\underline{2}$ (fig. 2b) possesses an anterior loop and three alternating triangles. This tooth corresponds in pattern to the second upper molar of *S. borealis*. $M\underline{3}$ (fig. 2a) may be described as having four simple transverse loops. The major transverse axis of the third transverse loop in contrast to those for the first and second loops intersects the anteroposterior axis of the tooth to form a large angle. The fourth transverse loop is reduced. The commissure between the third and fourth loops is situated on the internal side of the tooth. In contrast, the commissures separating the first three loops have an external position. $M\underline{3}$ differs from a comparable tooth in *Synaptomys borealis* in the less transverse position of the third loop, in shallower external re-entrant angles, and in the more nearly opposite position of the first external and internal re-entrant angles. In individuals of the Recent species the tooth is subject to considerable variation.



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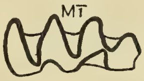

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FIG. 2—*Synaptomys vetus* n. sp. a, right $M\underline{3}$, No. 1367 C. I. T.; b, right $M\underline{2}$, No. 1366 C. I. T.; c, right $M\underline{1}$, No. 1365 C. I. T. x 6. Grand View, Idaho.

FIG. 3—*Synaptomys vetus* n. sp. Right $M\overline{1}$, No. 1364 C. I. T. x 6. Grand View, Idaho.

The pattern of $M\overline{1}$ (fig. 3) consists of a posterior loop, three alternating triangles, of which the external one is small and broadly confluent with the first internal one, and an anterior loop. The second external re-entrant angle is rather deep and more or less opposed to the third internal re-entrant.

The genus *Synaptomys* is divided into two subgenera, *Synaptomys* represented by the single Recent species *cooperi* and *Mictomys* represented by the single Recent species *borealis*.[1] The tooth pattern of the former is essentially as in the genus *Lemmus*. The latter subgenus is, on the other hand, distinguished from all other members of the *Lemmi* by the absence of external closed triangles in the inferior dentition, the buccal border being crenulated instead of possessing distinct salients and re-entrants. Absence of closed triangles on the external side of $M\overline{1}$ in *Synaptomys vetus* indicates a resemblance to *Mictomys*, but the first external re-entrant angle in this tooth is perhaps more prominent in *S. vetus* than in the latter subgenus, and the second external re-entrant angle is deep and seems to correspond more closely to the equivalent angle in the subgenus *Synaptomys*.

Comparisons—*Synaptomys vetus* apparently represents a form intermediate between the two Recent subgenera, *Synaptomys* and *Mictomys*, with perhaps closer relationship to *Mictomys* in so far as the tooth-pattern of the molars is concerned. In position of the grooves on the upper incisors, however, *S. vetus* may make a closer approach to individuals of the subgenus *Synaptomys*.

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[1] A. Brazier Howell, U. S. Dept. Agric., North American Fauna No. 50, 9, 1927.

The grooves in both subgenera are close to the outer borders of the teeth but the grooves in *Mictomys* are situated slightly nearer the median line. In *S. vetus* the grooves are situated close to the outer borders, a position more like that in *Synaptomys* than like that in *Mictomys*.

Only one fossil form of *Synaptomys* is close enough to *S. vetus* to warrant comparison, namely *S. cooperi annexus*[1] from the Frankstown Cave deposits. Although *S. c. annexus* was regarded as subspecifically distinct from the modern form, it appears to be entitled to full specific rank in the light of the characters shown in the figure of the type. None of the external triangles appears to be fully closed. In M$\overline{1}$ the dentine is confluent throughout the tooth and the anterior loop has a somewhat different outline from that in the Recent *S. cooperi*. The modern subspecies of *S. cooperi* show no marked differences in tooth-pattern.

Synaptomys vetus differs from *S. cooperi annexus* as follows: (1) outer triangle of M$\overline{1}$ much less definitely marked, especially in type of *S. vetus;* (2) anterior loop of M$\overline{1}$ shorter and with different outline; (3) salient angles sharper and re-entrant angles more alternating; and (4) considerably larger size (about 20 per cent). Recognition of the species *Synaptomys vetus* in the later Cenozoic emphasizes the fact that the immediate predecessor of *Synaptomys* should be sought for in the Tertiary rather than in the Quaternary.

Comparative measurements (*in millimeters*)

	Synaptomys vetus Calif. Inst. Tech. Coll. Grand View				*Synaptomys borealis wrangeli* Dickey Coll. Recent No. 9311
	No. 1365	No. 1366	No. 1367	No. 1364	
M$\underline{1}$, anteroposterior diameter	2.7	...	...	...	2.7
M$\underline{1}$, transverse diameter	1.3	...	...	...	1.2
M$\underline{2}$, anteroposterior diameter	...	2.0	...	...	2.0
M$\underline{2}$, transverse diameter	...	1.1	...	...	1.1
M$\underline{3}$, anteroposterior diameter	...	...	2.0	...	2.1
M$\underline{3}$, transverse diameter	...	...	1.0	...	1.0
M$\overline{1}$, anteroposterior diameter	...	...	...	3.0	2.9
M$\overline{1}$, transverse diameter	...	...	...	1.3	1.2

Mimomys (Cosomys) primus (Wilson)

Locality—Hagerman, Idaho.

Material—A right maxillary fragment with well worn M$\underline{1}$–M$\underline{3}$ in place, No. 12644 U. S. National Museum; a right ramus with M$\overline{1}$–M$\overline{3}$ also rather worn, No. 12633 U. S. Nat. Mus. (fig. 4b); a right ramus with M$\overline{1}$ and M$\overline{2}$, No. 12645 U. S. Nat. Mus. (fig. 4a); numerous fragments of rami with and without cheek-teeth; and isolated teeth comprising M$\underline{1}$–M$\underline{3}$ and M$\overline{1}$–M$\overline{3}$.

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[1] O. A. Peterson, Ann. Carnegie Mus., vol. 16, 277, fig. 4, 1926.

Relationships—This species was described originally from late Pliocene beds of the Coso Mountains, California. The new genus *Cosomys* was proposed to accommodate it. However, it was recognized that the form had many structural features in common with the extinct European genus *Mimomys.* The two genera were separated principally on the basis of fusion of the temporal ridges in the American form, a character not known to occur in *Mimomys.* Several structural features of minor importance, as well as the wide geographic separation of the two forms, were regarded as further evidence for recognition of the Californian form as a distinctive generic type. M. A. C. Hinton has objected to this generic separation, presenting cogent facts in support of his view.[1]

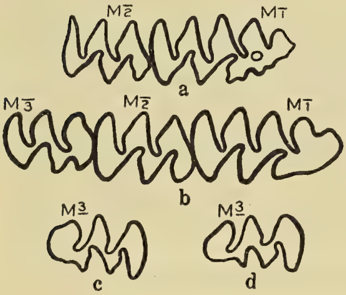

FIG. 4.—*Mimomys primus* (Wilson). a, incomplete lower right dentition No. 12645 U. S. Nat. Mus.; b, rather worn lower right dentition, No. 12633 U. S. Nat. Mus.; c, left $M\underline{3}$, No. 12964 U. S. Nat. Mus.; d, left $M\underline{3}$, No. 12965 U. S. Nat. Mus. x 6. Hagerman, Idaho.

Additional but likewise incomplete material of *Cosomys primus* from the later Cenozoic beds along the Snake River has served chiefly to increase the similarity between *Mimomys* and *Cosomys,* leaving only the fusion of the temporal ridges and the geographic separation as characters distinguishing the two genera. It is proposed therefore to refer *C. primus* to the European genus *Mimomys,* but to retain for the present *Cosomys* as a subgenus in view of the differences exhibited, particularly in development of the temporal ridges.

REVISION OF SPECIFIC CHARACTERS OF MIMOMYS (COSOMYS) PRIMUS

Specific characters—Teeth without cement. Third outer fold in $M\overline{1}$ reduced to form a pit surrounded by enamel as in *Mimomys pliocænicus.* Persistent "prism fold" in $M\overline{1}$. Second inner fold of $M\overline{3}$ not reduced by isolation of tip of this fold as in *M. pliocænicus.* $M\underline{1}$ and $M\underline{2}$ with three roots; remaining superior and inferior cheek-teeth with two roots each. Size approximately that of *M. pliocænicus.*

There can be little doubt that the Idaho species is identical with that described from the Coso Mountains. Selected individuals possess practically identical characters. Taking into account the individual variation shown by the Idaho material, no characters present themselves which might serve to distinguish specifically the forms known from the two localities.

The Idaho material furnishes added information regarding particular characters in *Mimomys primus.* No teeth were found with visible traces of cement, the Idaho specimens thus agreeing with the material from the Coso Mountains. Formation of the enamel islet in $M\overline{1}$ by an isolation of the tip of the third inner re-entrant angle and not by the third outer re-entrant was suggested in the original paper on *Cosomys.* Certain specimens in the Idaho collection clearly show the tip of the third outer re-entrant angle in process of isolation to form the islet. Thus the Idaho form agrees with the European species. Of the several available specimens of third upper molars (figs. 4c, 4d), none shows a tendency to isolate the tip of the second inner re-entrant. In *M. pliocœnicus,* the species resembling *M. primus* most closely in general characteristics, the tip is isolated. $M\underline{1}$ and $M\underline{2}$ are three-rooted, the remaining teeth being two-rooted. In $M\underline{1}$ the third small inner root supports the first closed triangle as in *M. pliocœnicus* In $M\underline{2}$ the third root is only slightly smaller than the other two. It supports the inner part of the anterior loop. This root is distinct from that supporting the outer part of the anterior loop, but in some specimens it shows a tendency to fuse to this root at the base.

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[1] M. A. C. Hinton, Jour. Mamm., vol. 13, 280-281, 1932.

Mr. Hinton has suggested that *Mimomys primus* and *M. pliocœnicus* are conspecific. The American species, however, appears to be distinguished from the European form by (1) absence of cement in the re-entrant folds, (2) lack of reduction of the tip of the second inner re-entrant angle on $M\underline{3}$, and possibly by (3) the union of the temporal ridges.

Comparative measurements of Mimomys primus (in millimeters)

	C. I. T. No. 500 Coso Mts.	U. S. Nat. Mus No. 12644 Hagerman	U. S. Nat. Mus. No. 12645 Hagerman	U. S. Nat. Mus. No. 12633 Hagerman
$M\underline{1}$, anteroposterior diameter......	2.7	2.7	...	...
$M\underline{1}$, transverse diameter...........	1.7	1.9	...	...
$M\underline{2}$, anteroposterior diameter......	2.1	2.1	...	...
$M\underline{2}$, transverse diameter...........	1.6	1.7	...	...
$M\underline{3}$, anteroposterior diameter......	2.1	2.2	...	...
$M\underline{3}$, transverse diameter...........	1.3	1.4	...	...
$M\overline{1}$, anteroposterior diameter......	3.2	...	3.1	3.2
$M\overline{1}$, transverse diameter...........	1.5	...	1.5	1.7
$M\overline{2}$, anteroposterior diameter......	2.0	...	2.0	2.2
$M\overline{2}$, transverse diameter...........	1.5?	...	1.5	1.5
$M\overline{3}$, anteroposterior diameter......	1.9	...	...	1.9
$M\overline{3}$, transverse diameter...........	1.1	...	...	1.4
Length of lower tooth row (crown). .	7.1	...	...	7.1

Mimomys? parvus n. sp.

Locality—Grand View, Idaho.

Type—No. 1369 Calif. Inst. Tech. Coll. Vert. Pale., an incomplete left ramus with $M\overline{1}$ and $M\overline{2}$ (fig. 6a).

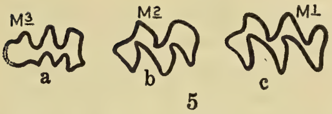
Paratypes—No. 1370, a left $M\underline{1}$; No. 1371, a left $M\underline{2}$; and No. 1372, a left $M\underline{3}$.

Referred material—Abundant but fragmentary material representing various lower jaws, with and without teeth, and numerous isolated cheek-teeth and incisors (Pl. 2, figs. 3, 4).

Specific characters—Anterior loop of $M\overline{1}$ cut by re-entrant angles isolating a fourth and fifth triangle, these triangles being more or less confluent with each other and with the anterior loop. First external triangle of $M\underline{3}$ reduced, external re-entrant angles shallow, and dentinal spaces of entire tooth broadly confluent. Dentinal spaces of remaining cheek-teeth somewhat confluent. Cheek-teeth without cement. Enamel not noticeably differentiated into thick and thin tracts. $M\underline{1}$ with three roots. Size small, but slightly larger than *Mimomys newtoni.*

Description—The description of the superior dentition is based entirely upon isolated teeth as no maxillary fragments bearing cheek-teeth have been obtained.

$\mathrm{M}\underline{1}$ (fig. 5c) and $\mathrm{M}\underline{2}$ (fig. 5b) possess a characteristic pattern. The first upper molar consists of an anterior transverse loop followed by four alternating and essentially closed triangles. The second upper molar has a transverse loop followed by three closed and alternating triangles. The single $\mathrm{M}\underline{3}$ (fig. 5a) available shows an anterior loop, two alternating triangles and a posterior loop. The dentinal spaces of the tooth are rather broadly confluent. The anterior loop is rectangular, the alternating triangles broadly confluent, the outer one reduced. The posterior loop is rather broad and possesses two small basal salient angles suggesting two additional triangles. The second inner re-entrant angle is directed transversely across the tooth-axis with no tendency to curve backward. The outer re-entrant angles are rather shallow. $\mathrm{M}\underline{3}$ differs from the corresponding tooth of *Mimomys primus* and probably from that in all other species of the genus in shallowness of the outer re-entrant angles and in the transverse rather than backward direction of the first internal re-entrant angle. In so far as can be determined from the specimen at hand, which represents the tooth of a young individual, reduction of the angle by isolation of the tip has not taken place as is the case in *M. pliocœnicus*. Further differences of minor character may be noted, but they lie possibly within the range of individual variation. $\mathrm{M}\underline{3}$ next to $\mathrm{M}\overline{1}$ is the most variable of the cheek-teeth. Since but a single specimen of $\mathrm{M}\underline{3}$ is available, the characters noted in this tooth may be subject to individual variation and may not always be especially diagnostic of this form. This tooth is similar to the corresponding tooth in certain species of *Alticola* and allied genera in the small size of the external triangle and in the confluency of that element with the anterior loop. However, in *Alticola* the first and second alternating triangles are shut off from each other. The first inner re-entrant angle is generally directed backward and the posterior part of the tooth is considerably narrower.


$\mathrm{M}\underline{3}$
$\mathrm{M}\underline{2}$
$\mathrm{M}\underline{1}$
a
b
c

5

FIG. 5—*Mimomys? parvus* n. sp. a, left $\mathrm{M}\underline{3}$, No. 1372 C. I. T.; b, left $\mathrm{M}\underline{2}$, No. 1371 C. I. T.; c, left $\mathrm{M}\underline{1}$, No. 1370 C. I. T. x 6. Grand View, Idaho.

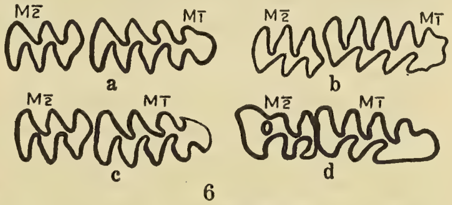


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FIG. 6—*Mimomys? parvus* n. sp. a, incomplete left lower dentition, No. 1369 C. I. T.; b, incomplete young right lower dentition, No. 1374 C. I. T.; c, worn left lower dentition, No. 1373 C. I. T.; d, very worn incomplete right lower dentition, No. 1375 C. I. T. x 6. Grand View, Idaho.

$\mathrm{M}\underline{1}$ possesses three roots, while the remaining cheek-teeth both above and below possess each but two roots. The third root of $\mathrm{M}\underline{1}$ is small and supports the first outer triangle.

The mandibular incisor passes from the lingual to the buccal side of the ramus apparently between $\mathrm{M}\overline{2}$ and $\mathrm{M}\overline{3}$. The incisor terminates proximally at a point situated slightly above the dental foramen.

$\mathrm{M}\overline{1}$ consists of a posterior loop, three alternating and closed triangles, and an anterior loop which is deeply cut on each side by re-entrant angles isolating a fourth and a fifth triangle. These triangles are more or less confluent with each other and with the anterior loop. In some specimens belonging to young individuals the anterior portion of the anterior loop is further complicated by several shallow re-entrant angles. The first lower molar is subject to noteworthy individual variation, clearly shown by the additional material available. The principal variations, apparently not particularly associated with age, are the greater or less confluency of the fourth and fifth triangles (figs. 6a, 6b), and the width of the dentinal commissure between the fifth triangle and the anterior portion of the loop. This portion of the loop also varies considerably but is usually sub-circular except for a distinct backwardly directed, basal angle on the buccal side which constitutes the fourth outer salient angle. In very worn specimens in which the lateral grooves are on the point of disappearance, only three triangles are present, the fourth internal re-entrant is shallow and the third external re-entrant has disappeared (fig. 6d).

$M\overline{2}$ consists of a posterior loop and four essentially alternating triangles with the third and fourth more or less confluent. This tooth also shows considerable individual variation. In some specimens the first and second triangles are somewhat confluent. In other specimens the last two triangles are wholly confluent and are replaced by what is essentially a transverse loop (figs. 6a, 6c). The two types of variation may be present in a single tooth.

The third lower molar has not been definitely recognized in the collections.

Comparisons—This small species of vole has been referred tentatively to the genus *Mimomys*. The genus is characterized by a first lower molar in which only three closed triangles precede the anterior loop. However, a more or less complete isolation of the fourth and fifth triangles occurs in *Mimomys? parvus*. In addition, the Idaho species possesses a rather distinctive $M\underline{3}$. Hence it seems possible that *M.? parvus* represents a distinct generic type. On the other hand the species is apparently closer to *Mimomys* than to any other genus, and although the characters separating *M.? parvus* and *M. primus* may appear at first sight to be of some magnitude, study of the European species of the genus reveals characters which to a certain extent bridge the gap between these two forms. Furthermore, it seems desirable when working with fossil forms to draw the generic lines somewhat more broadly than with Recent types. Additional material, especially of the superior and inferior third molars, doubtless will help to clarify the systematic position of this vole.

The genus *Mimomys* is divided into two groups, one characterized by reduction of the third outer re-entrant angle in $M\overline{1}$ (*pliocænicus* group), the other by retention of this angle as a deep re-entrant (*newtoni* group). *Mimomys? parvus*, if actually a member of that genus, falls within the second or *newtoni* group, and in tooth-pattern most closely resembles *M. majori* Hinton.[1] It is to be separated from the latter form by absence of cement in the lateral grooves of the cheek-teeth, the invariable absence of the "prism fold,"[2] presence of three roots on $M\underline{1}$, an earlier appearance of roots on the cheek-teeth, presence of a basal angle on the anterior portion of the anterior loop (fourth outer salient angle), and more particularly by the greater depth of the third outer and fourth inner re-entrant angles, thus causing a more or less complete isolation of the fourth and fifth triangles. $M\underline{3}$ differs apparently from the comparable tooth of *M. majori* in the characters enumerated under

[1] M. A. C. Hinton, Proc. Geol. Assoc., 21, 491, 1910; *Monograph of the voles and lemmings (Microtinæ) living and extinct*, vol. 1, 378-383, 1926.

[2] M. A. C. Hinton, *op. cit.*, 111, 1926.

the detailed description of that tooth. No figures of the third upper molar of *M. majori* are available for comparison. *M. majori* is a rather advanced member of the genus while *M? parvus* possesses several primitive characters, namely, well-developed roots on the cheek-teeth, presence of three roots on $M\underline{1}$, and lack of cement in the re-entrant folds of the cheek-teeth. Absence of a "prism fold" on $M\overline{1}$, a progressive character in the genus *Mimomys*, has been noted, however, in *M.? parvus*.

In tooth-pattern of $M\overline{1}$, *Mimomys? parvus* makes a close approach to certain specimens of *Microtus* (*Pedomys*) *haydeni*, *Neodon*, *Pitymys*, and allied genera. In these forms the first lower molar develops as characteristic features a posterior loop, five alternating triangles, the last two of which are more or less confluent, and an anterior loop. This loop is somewhat longer than the corresponding element in *M.? parvus*. In all of the above mentioned genera the cheek-teeth are without roots. However, the Idaho type can hardly be regarded as ancestral to the North American species *Microtus* (*Pedomys*) *haydeni* and to species of *Pitymys*, for representatives of *Microtus* and *Pitymys* are found in the upper Pliocene of England. These forms, like their modern representatives, possess teeth without roots. If, however, *Pedomys* is generically distinct from *Microtus*, as Hinton maintains, then *M.? parvus* may be regarded as ancestral to the former genus.

Measurements (*in millimeters*)

	No. 1370	No. 1371	No. 1372	No. 1369
$M\underline{1}$, anteroposterior diameter......	2.1	...	...	...
$M\underline{1}$, transverse diameter...........	1.3	...	...	...
$M\underline{2}$, anteroposterior diameter......	...	1.8	...	...
$M\underline{2}$, transverse diameter...........	...	1.1	...	...
$M\underline{3}$, anteroposterior diameter......	...	...	1.7	...
$M\underline{3}$, transverse diameter...........	...	...	0.9	...
$M\overline{1}$, anteroposterior diameter......	...	...	...	2.7
$M\overline{1}$, transverse diameter...........	...	...	...	1.3
$M\overline{2}$, anteroposterior diameter......	...	...	...	1.6
$M\overline{2}$, transverse diameter...........	...	...	...	1.1
$M\overline{1}$-$M\overline{3}$, alveolar length...........	...	...	...	6.3?
$M\overline{1}$-$M\overline{3}$, alveolar length (average of 5 specimens).................				6.1

Species of *Dolomys* Nehring[1] are to be distinguished from *Mimomys? parvus* by presence of five substantially closed and alternating triangles. Apparently no tendency toward confluency of the fourth and fifth triangles is evident in this genus as in *M.? parvus*. Moreover, the mandibular incisor extends slightly less backward than in our forms. The position of the posterior end of the incisor in *Dolomys* is on a level with or is slightly below the dental foramen, whereas in *M.? parvus* the posterior termination is slightly above the dental foramen. The third upper molar of *M.? parvus* differs distinctly from the comparable molar in *Dolomys bogdanovi* in shallowness of the second inner re-entrant angle and in absence of a second outer triangle. The only available figures of *Dolomys* were those of the Recent *D. bogdanovi* given by Hinton[2] and no detailed comparisons were made with the European fossil forms.

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[1] A. Nehring, Zool. Anz., 21, 13, 1898; M. A. C. Hinton, *op. cit.*, 339-348, 1926.

[2] M. A. C. Hinton, *op. cit.*, 347, fig. 98, 1926.

No figures of *Apistomys* Mehely are available for comparison, but according to Hinton[1] this extinct European genus is hardly to be distinguished generically from *Dolomys*.

Mimomys? parvus may be readily distinguished from *Clethrionomys* by the higher position of the proximal end of the mandibular incisor. In the Idaho type, as already stated, the tip of the incisor terminates above the level of the dental foramen, while in *Clethrionomys* it terminates below this opening. This difference likewise exists between *M.? parvus* and members of the genus *Phenacomys.* Moreover, the latter genus is characterized by lower molars in which the inner salients and re-entrants are considerably better developed than those of the buccal side. *Dolomys, Apistomys, Clethrionomys,* and *Phenacomys* agree with one another and with *M.? parvus* in the presence of roots on the cheek-teeth.

Ondatra idahoensis idahoensis n. sp. and n. subsp.

Locality—Grand View, Idaho.

Type—No. 1376 Calif. Inst. Tech. Coll. Vert. Pale.; an incomplete left ramus with $M\overline{1}$-$M\overline{3}$ (Pl. 2, figs. 1, 2; fig. 8c).

Paratypes—No. 1377, a right $M\underline{1}$; No. 1378, a right $M\underline{2}$; and No. 1379, a right $M\underline{3}$.

Additional material—No. 1380, a right ramus with $M\overline{2}$ and $M\overline{1}$ (fig. 8b); several fragments of rami with and without teeth; and numerous isolated teeth belonging to both inferior and superior dentitions.

Specific characters—$M\overline{1}$ with a posterior loop, five alternating triangles, and an interior loop of somewhat complicated pattern in the early stages of wear. No tendency of re-entrant angles to cut the anterior loop of $M\overline{1}$, isolating a sixth and seventh triangle as in Recent species of the genus. Dentinal spaces of teeth confluent. $M\underline{3}$ with a rather shortened posterior loop. Teeth without cement. $M\underline{1}$ possesses three roots. Roots of cheek-teeth developing somewhat earlier than in Recent species. Size small, somewhat smaller than *Ondatra annectens* and about as in *Neofiber alleni.*

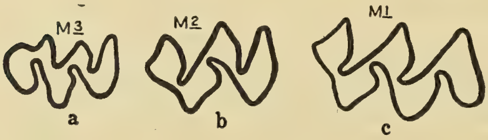

FIG. 7—*Ondatra idahoensis idahoensis* n. sp. and n. subsp. a, right $m\underline{3}$, No. 1379 C. I. T.; b, right $M\underline{2}$, No. 1378 C. I. T.; c, right $M\underline{1}$ No. 1377 C. I. T. x 6. Grand View, Idaho.

Subspecific characters—Size slightly larger than *Ondatra idahoensis minor.* Average length of $M\overline{1}$ 10 per cent greater. Anterior wall of third outer re-entrant angle with distinct backward curvature.

Description—*Ondatra idahoensis idahoensis* is somewhat smaller than the extinct species *O. annectens,* heretofore the smallest known species of the genus. Among Recent voles, our form compares favorably in size with *Neofiber alleni.*

The first upper molar (fig. 7c) exhibits on the occlusal surface an anterior loop and four alternating triangles. The tooth has a characteristic pattern and does not differ essentially from that in Recent *Ondatra.* $M\underline{1}$ possesses, however, three roots instead of two, the small third root supporting the first closed triangle. In addition, the dentinal spaces of the tooth are confluent. Moreover, confluency of the dentinal spaces is a distinctive character for all of the cheek-teeth of *Ondatra idahoensis.* In Recent *Ondatra* the alternating triangles are very tightly closed. $M\underline{2}$ (fig. 7b) presents an anterior loop and three alternating triangles. This tooth is also of normal pattern and agrees closely in structure with the corresponding tooth in Recent *Ondatra*. M$\underline{3}$ (fig. 7a) possesses a transverse loop, two alternating triangles and a posterior loop. It differs from the corresponding tooth in Recent species of *Ondatra* in the anteroposterior shortening of the posterior loop.

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[1] M. A. C. Hinton, *op. cit.*, 349, 1926.

The mandibular incisor crosses from the lingual to the buccal side, apparently between M$\overline{2}$ and M$\overline{3}$, and terminates above the dental foramen. Its termination is indicated by a pronounced hump developed on the external surface of the ascending ramus. M$\overline{3}$ is not noticeably displaced by the incisor. A slight displacement of M$\overline{2}$ appears to take place in some specimens.

The occlusal surface of M$\overline{1}$ is composed of a posterior loop, five alternating triangles, and an anterior loop possessing complications (fig. 8b) in an early stage of wear. The first lower molar of *Ondatra idahoensis* differs from the corresponding tooth in known species of *Ondatra* in the reduction of the re-entrant angles cutting the anterior loop. Even in very young specimens the re-entrant angles cutting the anterior loop of this tooth are present as rather shallow infolds. The latter are probably no better developed than the early complications present in some individuals of *Neofiber*. Usually in Recent

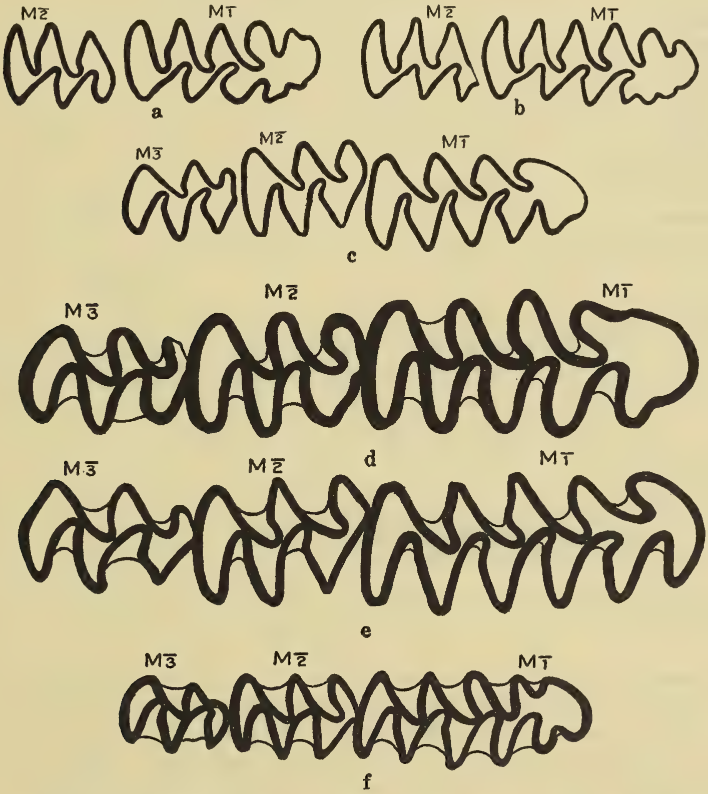


FIG. 8.—a, *Ondatra idahoensis minor* n. subsp. Incomplete right lower dentition, No. 12624 U. S. Nat. Mus., Hagerman; b, *Ondatra idahoensis idahoensis* n. sp. and n. subsp., incomplete right lower dentition, No. 1380 C. I. T., Grand View; c, *Ondatra idahoensis idahoensis* n. sp. and n. subsp., left lower dentition, No. 1376 C. I. T., Grand View; d, *Ondatra zibethica osoyoosensis* (Lord), left lower dentition, No. 8463 Dickey Coll., Recent, Idaho; e, *Ondatra zibethica osoyoosensis* (Lord), left lower dentition, No. 17875 Dickey Coll., Recent, British Columbia; f, *Neofiber alleni* True, left lower dentition, No. 9742 Dickey Coll., Recent, Florida. x 6.

specimens of the genus, the fourth external and the fifth internal re-entrant angles cut the anterior loop deeply enough to isolate a sixth and seventh triangle (fig. 8e). However, some specimens, apparently after considerable wear, present a pattern comparable to that in O. *idahoensis* (cf. figs. 8c and 8d). In the latter form the absence of the sixth and seventh triangles is constant in the material available. Reduction of the fourth external and fifth internal re-entrant angles is not shown in other fossil species of *Ondatra.* In the first lower molar of *O. oregona* and *O. annectens* these angles are deeper than in any existing species, and in the case of the only other known fossil species,

Comparative measurements (*in millimeters*)

	O. i. idahoensis Calif. Inst. Tech. Grand View		*O. i. minor* U. S. N. M. Hagerman No. 12624	*O. annectens* A. M. N. H. Conard Fissure No. 12424	*O. zibethica osoyoosensis* Dickey Coll. Recent No. 17875
	No. 1376	No. 1380			
M$\overline{1}$, anteroposterior diameter	4.9	4.6	4.3	5.7	7.4
M$\overline{1}$, transverse diameter	2.2	1.8	1.9	....	3.1
M$\overline{2}$, anteroposterior diameter	2.8	2.4	2.6	....	3.7
M$\overline{2}$, transverse diameter	2.1	1.6	1.8	....	2.7
M$\overline{3}$, anteroposterior diameter	2.5	...	...	....	3.6
M$\overline{3}$, transverse diameter	1.7	...	...	....	2.4
M$\overline{1}$-M$\overline{3}$, (crown length)	10.2	...	...	12.0 (alveolar length)	14.6

	Anteroposterior diameter	Transverse diameter
M$\underline{1}$, No. 1377, C. I. T.	3.6	2.1
M$\underline{2}$, No. 1378, C. I. T.	2.7	1.9
M$\underline{3}$, No. 1379, C. I. T.	*a*2.4	*a*1.5
M$\overline{1}$, Grand View loc. average of six specimens	4.7	2.1
M$\overline{1}$, Hagerman loc. average of six specimens	4.2	1.9

a, Approximate.

O. nebrascensis, the angles are as in the more normal Recent individuals of the genus.[1] In this character *O. idahoensis* agrees more nearly with *Neofiber* (fig. 8f). M$\overline{2}$ possesses a posterior loop and four alternating triangles. M$\overline{3}$ consists of a posterior loop, three alternating triangles, and a fourth small antero-external triangle which is broadly confluent with the antero-internal one. In M$\overline{3}$ three external salient angles are present as in known species of *Ondatra,* while two only are found in *Neofiber* (cf. figs. 8c, 8d, and 8f). Some Recent specimens of *Ondatra* apparently possess only two salients,[2] but so far as is known two is the maximum number found in *Neofiber.*

[1] N. Hollister, U. S. Dept. Agric., North American Fauna No. 32, 32-34, 1911.

[2] N. Hollister, *op. cit.*, 34, 1911.

In addition to the characters discussed above, *Ondatra idahoensis* differs from all other described species of *Ondatra* in the absence of cement on the cheek-teeth. It differs from Recent species of *Ondatra*, and perhaps from described fossil species as well, in an earlier development of roots in the cheek-teeth. In a jaw of the Idaho form where the transitory complications of the anterior loop of $M\bar{1}$ are still present, the pulp cavities of $M\bar{3}$ are closed. In Recent *Ondatra* this tooth, in contrast to the remaining cheek-teeth, shows the smallest development of roots.

In the pattern of the cheek-teeth and especially in that of the first lower molar, *Ondatra idahoensis* approaches *Neofiber*. However, the Idaho type is quite distinct generically from this form. The cheek-teeth of *Neofiber* grow with a persistent pulp-cavity present in contrast to the rather early development of roots in the cheek-teeth of *O. idahoensis*. Differences of less importance which distinguish *O. idahoensis* from *Neofiber* are: (1) $M\bar{3}$ with three outer salients instead of two, (2) teeth lacking cement, and (3) dental foramen of ramus situated somewhat above the posterior notch as in Recent *Ondatra* and not nearly opposite this notch as in a compared specimen of *Neofiber*.

Ondatra idahoensis minor n. subsp.

Locality—Hagerman, Idaho.

Type—No. 12624 U. S. Nat. Mus., an incomplete right ramus with $M\bar{1}$-$M\bar{2}$ (fig. 8a).

Additional material—No. 12623 U. S. Nat. Mus., a left ramus with $M\bar{1}$-$M\bar{3}$; Nos. 12625-12627 U. S. Nat. Mus., incomplete rami; and various isolated cheek-teeth.

Subspecific characters—Size averaging slightly smaller than *Ondatra idahoensis idahoensis*. Average length of $M\bar{1}$ 10 per cent smaller. Anterior wall of the third outer re-entrant angle nearly transverse with respect to tooth-axis.

Remarks—This form is very close to *Ondatra idahoensis idahoensis*, but appears to be distinguished from it by the characters cited above. Further differences are to be noted but do not seem to be constant throughout the material. Thus, the fourth and fifth triangles of $M\bar{1}$ are rounded, especially the fourth, and the fourth and fifth triangles of this tooth are slightly more confluent with the anterior loop than in *O. i. idahoensis*.

It is possible that the characters separating the subspecies *minor* and *idahoensis* are more apparent than real. However, the available material, which is relatively abundant, appears to justify subspecific separation of the Hagerman type. The geographic separation of the two forms likewise may suggest the presence of two distinct races.

For measurements, see table of comparative measurements under the discussion of *Ondatra idahoensis idahoensis*.

Plate 1

Castor cf. *accessor* Hay

Figs. 1, 1a.—Right M$\underline{1}$, No. 1361 C. I. T., Grand View, Idaho; x 2. Fig. 1, occlusal view; fig. 1a, external view.

Fig. 2.—Left M$\underline{3}$ No. 1362 C. I. T., Grand View, Idaho; x 2.

Figs. 3, 3a.—Fragmentary right ramus with M$\overline{1}$, No. 1360 C. I. T., Grand View, Idaho; x 2. Fig. 3, external lateral view; fig. 3a, occlusal view.

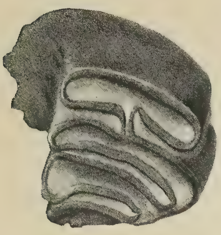
Fig. 5.—Left M$\underline{2}$, No. 1363 C. I. T., Grand View, Idaho; x 2.

Thomomys gidleyi n. sp.

Figs. 4, 4a.—Left ramus of mandible, No. 12651 U. S. Nat. Mus., Hagerman, Idaho; x 6. Fig. 4, external view; fig. 4a, occlusal view.

Citellus? species

Fig. 6.—Right P$\overline{4}$, No. 12963 U. S. Nat. Mus., Hagerman, Idaho; x 6.



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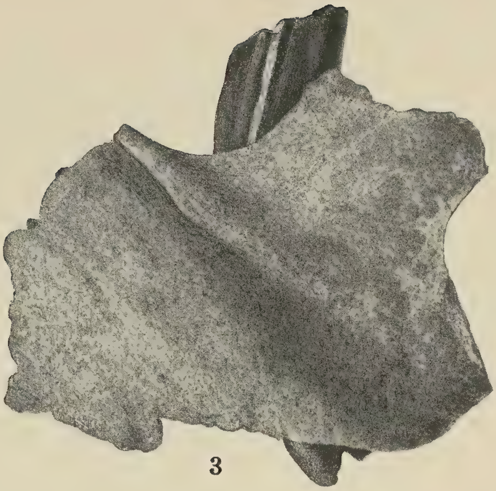

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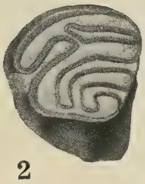

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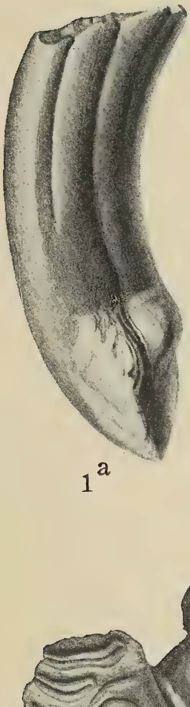

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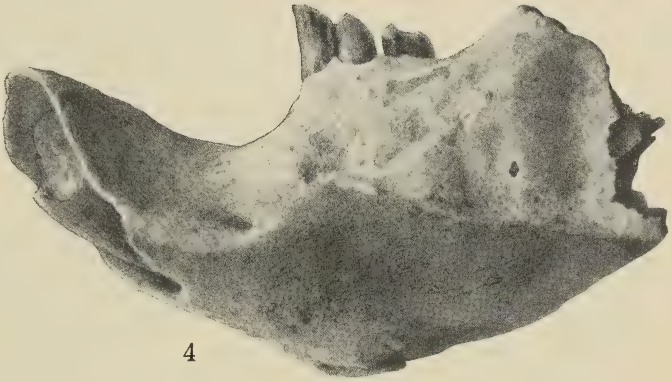

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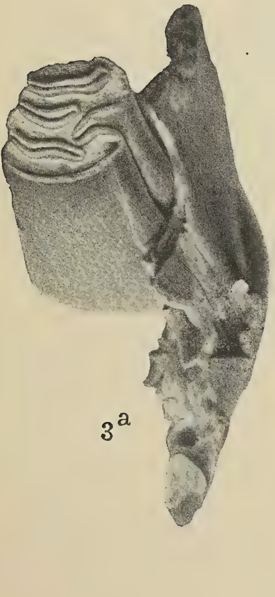

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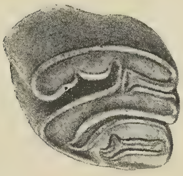

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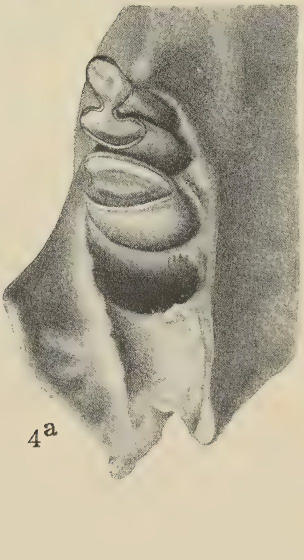

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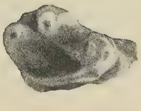

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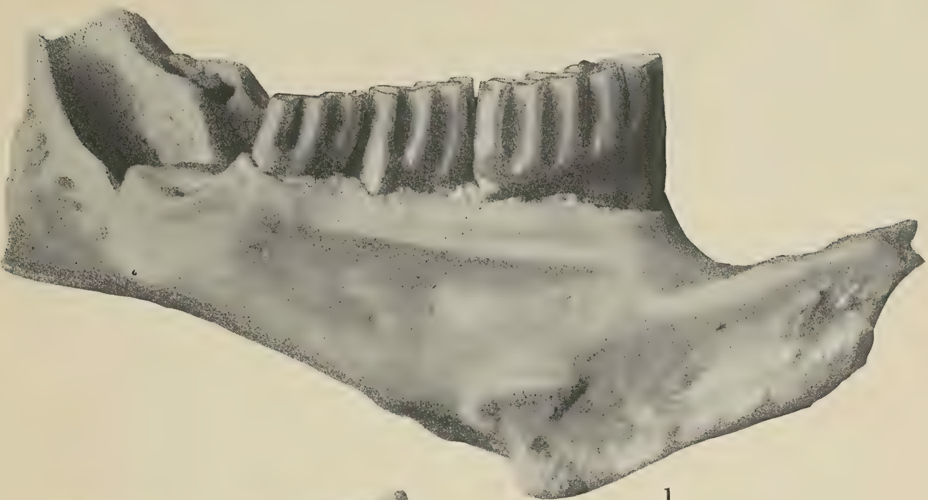
PLATE 2

FIGS. 1, 2.—*Ondatra idahoensis idahoensis* n. sp. and n. subsp. Left ramus of mandible, No. 1376 C. I. T., Grand View, Idaho; x 5. Fig. 1, internal view; fig. 2, external view.

FIGS. 3, 4.—*Mimomys? parvus* n. sp. Right ramus of mandible, No. 1375 C. I. T., Grand View, Idaho; x 5. Fig. 3, external view; fig. 4, internal view.



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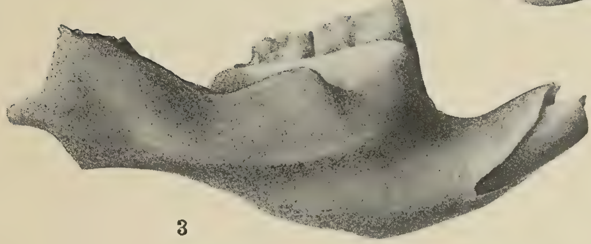

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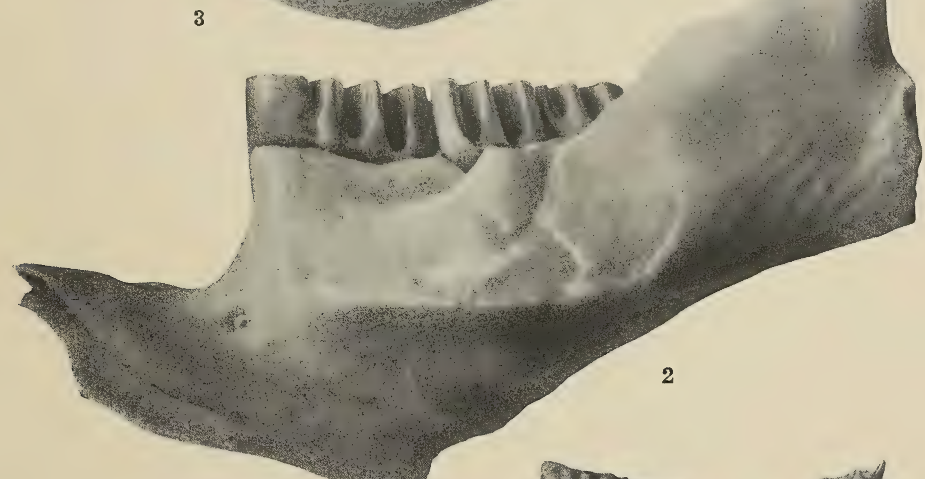

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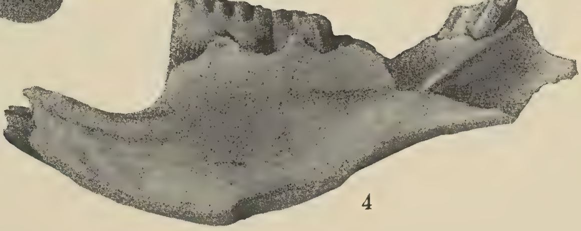

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